USAARL Report No. 97-06

Physiological and Psychological Effects of Thermally Stressful UH-60 Simulator Cockpit Conditions on Aviators Wearing Standard and Encumbered Flight Uniforms

By

Matthew J. Reardon
Nicholas Smythe, III
Julia Omer
Beth Helms
J. Darrell Hager
Marjorie Freeze
Donna Buchanan

Aircrew Health and Performance Division

December 1996

U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 70-25 on Use of Volunteers in Research.

Reviewed:

JEFFREY C. RABIN
LTC, MS
Director, Aircrew Health and
Performance Division

Released for publication:

JOHN A. CALDWELL, Ph.D.
Chairman, Scientific
Review Committee

DENNIS F. SHANAHAN
Colonel, MC, MFS
Commanding

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 97-06	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) MCMR-UAS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-0577	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
0602787A	3M162787A879	OD	179

11. TITLE (Include Security Classification)
(U) Physiological and Psychological Effects of Thermally Stressful UH-60 Simulator Cockpit Conditions on Aviators Wearing Standard and Encumbered Flight Uniforms

12. PERSONAL AUTHOR(S)
M.J. Reardon, N. Smythe, III, J. Omer, B. Helms, J.D. Hagar, M. Freeze, D. Buchanan

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM TO	1996 December	106

16. SUPPLEMENTAL NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
23	01	
24	07	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
aviator battle dress uniform

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
A repeated measures, 2 by 2 factorial study, using 14 aviators (17 test iterations) evaluated the effects of the four combinations of unencumbered MOPP0 aviator battle dress uniform (ABDU) and encumbered MOPP4 over ABDU flight ensembles in cool (70°F, 50 percent relative humidity [RH]) and hot (100°F, 50 percent RH) UH-60 cockpit conditions. This report describes the physiological and psychological responses. The most striking, operationally relevant result was that none of the crews in the encumbered MOPP4-hot condition were able to complete the first two 2-hour sorties. The current encumbered MOPP4 aviator uniform in hot conditions decreased average mission endurance from the fully completed mission time of 309 minutes (range: 347-288) to 107 minutes (range: 154-40). The reduced endurance was due to rapid increases in core temperature (0.73°F/hour compared to 0.27°F/hour for the MOPP0-cool condition), progressive physical discomfort and psychological stress, and adversely affected mood. Calculated total body heat storage for the encumbered MOPP4-hot condition was 1445 watts compared to 627 watts for the MOPP0-hot condition. In the encumbered MOPP4-hot condition, heart rate rapidly increased to an average maximum of 142 (range: 170-119) beats per minute (bpm) during the (continued)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE (Include Area Code) (334) 255-6907 22c. OFFICE SYMBOL MCMR-UAX-SI

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

DD FORM 1473 (Continued)

19. Abstract

simulated preflight on a treadmill, and then remained elevated with an average of 133 bpm (range: 164-102) and average maximum of 143 bmp (range: 170-119) during the simulator sorties. The heart rate in the other hot condition (ABDU MOPP0) rose to moderately high levels with an average maximum of 100 bmp (range: 122-73) during the simulated preflight inspection on the treadmill, reduced after the treadmill session was completed, but then increased again in the simulator to an average maximum of 111 bpm (range: 135-91). Heavy sweat rates while in the MOPP4-hot condition (1523 cc/hour compared to 92.2 cc/hour during the MOPP0-cool condition) led to significantly greater amounts of dehydration (2.25 percent compared to 0.18 percent during the MOPP0-cool condition) over shorter periods of time. Compared to the least thermally stressful condition (ABDU MOPP0-cool), mean chest temperature was 1.52°F greater in the encumbered MOPP4-cool condition, 1.85°F greater in the ABDU MOPP0-hot condition, and 4.68°F greater in the encumbered MOPP4-hot condition. The overall correlation between chest and core temperatures was 0.82. The encumbrance and thickness of the ensemble also, depending on seat position, restricted the range of aft cyclic movements. The results of this evaluation suggest that future rotary-wing aviator flight uniform components should be designed to be lighter weight and allow greater evaporation of sweat. Methods should be sought to improve fit and comfort, particularly for the mask and helmet combination, as well as prevent pressure discomfort over the back due to the life raft. The 11.7 lb ballistic protective plate also should be lighter weight and reduced in thickness. Forced dry air microclimate cooling into the ensemble should be considered for reducing heat accumulation in the encumbered MOPP4 aviator ensemble by enhancing evaporative cooling and thereby increasing endurance times during hot weather operations.

Acknowledgments

The 1996 Air Warrior Heat Stress research team would like to acknowledge the many additional USAARL personnel who contributed to the successful completion of this study. CW5 (ret) Larry Woodrum took the basic concepts for the flight profiles and generated detailed flight scripts. Mr. Art Estrada served as the simulator operator for almost the entire duration of the study. His consistent interaction with, and cueing, the volunteer pilots with respect to starting and stopping the flight maneuvers obviated what would have been an extraordinarily tedious process of manually "trimming" the raw flight performance data streams. Al Lewis, USAARL's biomedical engineer, and Bob Dillard, electronics technician, did a wonderful job building, testing, calibrating, and troubleshooting the data acquisition system in the UH-60 simulator. They also corrected occasional problems with the heat lamps, sensor harnesses, heart rate counters, and treadmills. Dr. Heber Jones and Andy Higdon set up the database files and software for the "HAWK" UH-60 simulator data acquisition systems and assisted in accessing the physiological and flight performance data. James Burkett did a masterful job building and installing the fold-away stand into the simulator for the multi attribute task battery computer performance test. Dan Ranchino assisted with PC hardware and software problems. We also are grateful to the Aircrew Protection Division for trouble-free access to their environmental chambers. Lastly, SGT Roger Jones provided important assistance with recruitment of volunteer participants. All these individuals were a pleasure to work with due to their professionalism, special expertise, and persistence in the face of difficulties.

Table of contents

Page

Introduction.......... 1

Military relevance.......... 1

Principal study objectives.......... 1

Background.......... 2

Environmental and mission related heat stress factors.......... 2

Review of thermal stress physiology.......... 3

Effects of heat stress and CD protective ensembles on Army aviators.......... 7

Methods and procedures.......... 7

Study design.......... 7

Enviromental conditions.......... 8

Flight uniforms.......... 8

UH-60 simulator flight missions.......... 13

Physiological.......... 14

Measurement of heart rate 14

Measurement of body core temperature.......... 14

Measurement of skin temperature.......... 17

Measurement of dehydration.......... 17

Psychological.......... 18

Mood and symptoms.......... 18

Profile of mood states.......... 18

Task load index.......... 18

Sequence of events in the study.......... 19

Table of contents (continued)

Page

Results 21

Test subjects 22

Environmental conditions 22

Physiological results 24

Endurance 24

Heart rate 24

Core temperature 28

Skin temperature 36

Fluid balance and dehydration 38

Psychological results 43

Uniform associated pressure-point (hot spot) discomfort 43

Mood and symptoms 43

Profile of mood states 47

Task load index 47

Correlations and regressions 47

Discussion 53

Comparison of results with previous USAARL heat stress studies 54

Conclusions 57

References 58

Table of contents (continued)

Page

Appendices

A. Data tables 61

B. MANOVA and ANOVA results tables 71

C. Correlation tables 77

D. Test session run identifiers 89

E. Questionnaires 91

F. Data collection forms 95

G. Checklists and procedures 98

H. Manufacturers and product information 101

List of figures

1. Photos of aviator uniform components 11

2. Rectal thermistor 15

3. Thermistor calibration 15

4. CorTemp system 15

5. Heat stress study process 20

6. Demographics charts 23

7. ANOVA results for UH-60 simulator temperatures and relative humidity 25

8. Endurance time profiles 26

9. Average heart rate profiles 27

10. Average and maximum heart rate charts 27

11. Rate of change graphs for heart rate 29

12. Average core temperature profiles 30

Table of contents (continued)

Figure		Page
13.	Average and maximum core temperature charts	30
14.	Rate of change graphs for core temperature	32
15.	Outer surface temperatures	33
16.	Cumulative heat storage time profiles	34
17.	Rectal thermistor versus CorTemp pill	37
18.	Skin temperature graphs	39
19.	Rate of change graphs for skin temperature	40
20.	Sweat loss profiles	41
21.	Means for sweat and fluid balance	42
22.	Hot spot distribution charts	44
23a.	Hot spot intensity charts	45
23b.	Hot spot intensity charts (cont.)	46
24a.	Mood and symptom detail category charts	48
24b.	Mood and symptom detail category charts (cont.)	49
25.	Means for questionnaires by condition	50
26.	Profile of mood states: Pre- and posttest results	51
27.	TLX response charts	52

List of tables

1.	Incomplete counterbalancing of test conditions	9
2.	Encumbered MOPP4 heat stress study aviator ensemble	10
3.	Current flight uniform component weights	12
4.	CorTemp inaccuracy table and graph	35
5.	Core and skin temperature means and ranges by condition	36

Introduction

Military relevance

Air Warrior is an interservice (Army, Navy, and Marines) long range research and development project for incrementally developing state-of-the-art rotary-wing flight uniforms by using an integrated soldier-system design methodology. These new-generation flight ensembles will be modular, mission configurable, nuclear, biological, chemical(NBC)-capable, and complemented with advanced life support and ballistic protection components (ATCOM, ORD, 1995). The primary Air Warrior goal is to enhance aviator effectiveness and survivability when conducting military operations in conditions exposing them to a variety of mission-related performance and survivability risks.

The current encumbered MOPP4 over aircrew battle dress uniform (ABDU) system utilizes the standard ABDU as well as the battle dress overgarment (BDO). The BDO is worn over the ABDU to protect against chemical warfare threats. An aviation life support equipment (ALSE) vest and a thick laminated ballistic plate for chest protection are worn over the BDO. When worn together, the encumbered MOPP4 over ABDU flight uniform and accessory components create a bulky ensemble that significantly encumbers the aviator and would impair thermoregulation and heat dissipation. For this reason, it was necessary to quantitatively characterize the potential adverse physiological and psychological effects of an encumbered MOPP4 aviator ensemble in simulated hot weather conditions so that enhanced components can be designed with properties that mitigate heat stress and improve endurance, flight performance, and comfort.

Principal study objectives

The data collection portion of the this study was conducted from 25 March to 2 August 1996 at the U. S. Army Aeromedical Research Laboratory (USAARL). It was implemented to fulfill the collaborative U.S. Army Aviation and Troop Command (ATCOM) directed objectives as indicated in the governing Statement of Work (USAARL, SOW, 1995). The two primary objectives of the study were the following:

1. Develop and test a methodology for evaluating the extent to which current and future versions of the encumbered MOPP4 over ABDU aviator ensemble contribute to heat strain and affect flight performance, mission accomplishment, endurance, and mood states in hot versus temperate UH-60 simulator cockpit conditions.
2. Establish a baseline heat stress effects profile for the current encumbered MOPP4 over ABDU ensemble against which enhanced versions of the ensemble may be compared as they are developed.

Background

Environmental and mission related heat stress factors

During NBC threat scenarios, helicopter pilots must fly with doors and windows closed in order to minimize potential ingress of liquid or vapor chemical warfare agents into the aircraft cabin. Unfortunately, in areas with hot sunny weather, a closed unairconditioned aircraft cabin will cause increased pilot heat stress due to heat transfer from the environment and helicopter systems such as engine component and electronic modules, direct solar radiation, and the occurrence of greenhouse effects within the cockpit.

The greenhouse effect involves the increase in heat stress due to absorption of infrared (IR) energy by the elevated concentrations of carbon dioxide and water vapor within an enclosed crew compartment (Considine and Considine, 1983). The majority of the solar energy entering a cockpit lies within the visible electromagnetic (EM) band and is not well absorbed by the air. Depending on the wavelength dependent absorptivity and transmissivity of the numerous surfaces within a cockpit, varying amounts of incident solar radiation can be absorbed by surface materials and personnel within the cockpit (Wentworth et al., 1995). The absorbed energy causes an increase in surface temperatures. The heated surfaces then re-emit a portion of the absorbed solar energy. Because surface temperatures are low (~150°F) compared to the effective solar temperature (10,160°F), the reradiated energy, according to Wein' displacement law (Hudson, 1969), has a significantly lower energy density (longer wavelength) spectrum centered in the IR band (peak at ~8.5 microns). This frequency shift in the energy density profiles for incident and reradiated EM energy represents a nonlinear effect of the cockpit and crew surfaces on incident solar radiation.

Because of the greenhouse effect, a closed cockpit in hot weather conditions without a cockpit cooling system (not currently available for the UH-60) will result in internal dry bulb temperatures that are significantly greater than when flying with the doors and windows open. The humidity within a closed, or poorly ventilated, cockpit will be greater than outside humidity due to an accumulation of water vapor from breathing, transcutaneous water losses, and evaporation of sweat. The combination of increased dry bulb temperature and humidity, as well as reduced airflow, results in a significant increase in cockpit wet bulb globe temperature (WBGT) above the external, or ambient, WBGT.

Thornton and Guardiani (1992), for example, determined that during summer flights within a closed hovering UH-60, there was an average 5°C (9°F) increase in cockpit WBGT relative to the external WBGT device which typically recorded ~30°C (86°F). Although outdoor humidities were not measured, within the closed cockpit the humidity was generally between 40-60 percent. Incident radiation at the level of the pilot's head averaged 650 watts/meter^2.

An earlier study (Breckenridge and Levell, 1970), conducted during the summer at the Hunter Army Airfield in Georgia, revealed even more serious greenhouse effects (10-20°F increases in cockpit vs external WBGTs) within the closed cockpit of an AH-1G helicopter. Internal dry bulb temperatures often were between 130-135°F. Cockpit humidity was not reliably measured but 45 percent was considered representative. Also, radiant heat load was not directly measured. One of the conclusions of the study was that even if pilot metabolic rates are as low as 135 watts, heat accumulation will occur when cockpit WBGT reaches or exceeds 80°F.

Since the WBGT has been validated as an indicator of physiological heat stress, elevated WBGTs in closed cockpits are associated with a greater degree of aircrew heat strain compared to the lower WBGTs that occur when flying with windows and doors open. Measurable physiologic and psychological strain occurs in individuals exposed to thermally stressful conditions. Excessively intense or prolonged heat stress exposure will eventually lead to a spectrum of different heat illnesses (e.g., Kerstein et al., 1984) or even sudden collapse with few if any premonitory symptoms (Mitchell, 1991).

Prior to conducting this study, the thickness and occlusiveness of the current encumbered MOPP4 ensemble was presumed to impose considerable resistance to transfer of heat energy from the aviator to the environment. It was expected that it would partially or totally impair the transport and evaporation of sweat through the uniform, particularly over parts of the body, such as the chest, that would be covered with the protective ballistic plate. Additionally, the weight and encumbrance of the BDO, protective mask and hood, ALSE vest, and ballistic protection plates was likely to hinder certain movements and possibly increase the basal metabolic rate. It was also expected that the rate that air is pumped through the uniform also would be reduced. Therefore pilots wearing the encumbered MOPP4 ensemble, were considered likely to experience reduced convective and evaporative cooling capability as compared to aviators wearing just the ABDU and ALSE vest without the additional components of the encumbered MOPP4 ensemble.

Review of thermal stress physiology

Heat stress induces many complex and interrelated compensatory physiological and biochemical thermoregulatory changes or adaptations which are collectively termed heat strain (Wyndham, 1973). The overall effect of properly functioning heat strain responses is dissipation of excess heat energy that accumulates within body compartments (blood, brain, muscle, abdominal organs. etc).

The efficiency of thermoregulation may be adversely affected by environmental conditions, uniform, and aviator characteristics. Ambient humidity may also be sufficiently great that sweat can not completely evaporate before it falls off the skin onto the ground or into the clothing. Excessive insulation and low permeability of uniform components to sweat will cause increased resistance to heat transfer from skin to

ambient air. Individual aviator factors that can impair thermoregulation include health status, dehydration, medications, and skin condition.

It is a basic biophysical principal that core temperature increases in proportion to the amount of heat energy stored within body tissues and fluids. The proportionality constant for this biophysical relationship is the body's average specific heat capacity which is normally 3.49 kJ/(kg*C). If endogenous or exogenous factors cause heat storage within the body, core temperature increases and compensatory protective heat dissipating processes are progressively activated. The primary thermoregulatory processes include sweating, peripheral vasodilation, increased cardiac output, and shunting of blood flow from visceral organs to the skin and the working muscles producing heat. Sweating rate, heart rate, blood pressure, and other physiological measures comprise the readily measured physiological reactions to heat stress; i.e., the clinically detectable components of heat strain. Other heat strain effects, such as elaboration of protective heat shock proteins (Schlesinger and Collier, 1991), occur at the cellular and biochemical level and require blood tests or other methods for detection.

In addition to environmental factors, elevated metabolic rate is usually an important, or sometimes the primary, cause of core temperature elevation. However, even a low metabolic rate; e.g., associated with sedentary activities in an environmentally uncompensable heat stress situation, can lead to inexorable elevations in core temperature and eventually heat illness. If heat accumulation due to storage of thermal energy from metabolic processes equals or exceeds the body's maximum heat dissipating capability, core temperature will not reach a tolerable equilibrium but will rise continuously in direct proportion to the duration and intensity of the work rate. In other words, in such circumstances, the slope of the core temperature profile is a function of the metabolic rate. For these situations, endurance can be extended by using work-rest cycles, engineering controls to improve work efficiency, microclimate cooling, or relocation of the activity to a cooler location.

Metabolic rates for routine flight maneuvers in military helicopters are rather low (100-200 watts) (Thornton et al., 1984). This range of metabolic rates places such activity in the category of very light to light physical work. Therefore, for most circumstances, the contribution of metabolic rate to core temperature elevations in helicopter pilots in hot conditions will be relatively small over a short period of time. However, if the ambient or cockpit conditions are sufficiently hot, core temperature may progressively increase anyway, due to high rates of passive heat gain, to levels that can impair performance and cause heat illness.

Depending on a variety of factors, thermoregulatory responses to heat stress may have complete, partial, or no beneficial effect. Thermoregulatory effectiveness is a function of the balance between external and internal (metabolic rate) heat gain as well as the capabilities and limitations of the heat strain mechanisms. Completely effective thermoregulatory responses to heat stress will prevent core temperature from rising

above normal. Indicators of heat stress in such circumstances will consist of elevated heart rate, increased skin blood flow, and sweating. When exposed to compensable heat stress conditions, heat storage occurs initially, but the rate of heat storage is eventually reduced to zero by negative feedback thermoregulatory mechanisms. This results in a core temperature profile which asymptotically approaches a tolerable, but elevated, steady-state level.

Heat stress may be sufficient to overwhelm an individual's maximum thermoregulatory capabilities (which may have been reduced or below average due to dehydration, illness, or other stressors). This type of situation indicates the presence of uncompensable heat stress. In such circumstances, core temperature will inexorably rise beyond tolerable levels. Thermoregulatory mechanisms tasked to their maximum may delay but not prevent this inevitable outcome. Eventually the individual will be incapacitated by the adverse effects of increasing heat storage and rising core temperature. If this type of thermally oppressive environment cannot be avoided by modifying the mission, an effective strategy for maintaining survivability and sustaining performance is the use of macroclimate (air conditioning) or microclimate (personal) cooling devices.

Data from previous heat stress studies indicated that the hot environmental condition used in this study; i.e., 37.8°C (100°F) dry bulb temperature and 50 percent relative humidity (RH), would likely impose marginally compensable heat stress for our volunteers. That is, it was very likely that aviator volunteers with lower than average thermoregulatory capabilities would exceed their physiological and psychological heat stress tolerance levels. Biophysical coefficients for the encumbered MOPP4 ensemble with the ALSE survival armor recovery vest, insert and packets (SARVIP), and ballistic protective components were not available to allow the use of heat strain models to accurately predict heat stress tolerance times.

In Thornton's heat stress study (1992), the aviators wearing the MOPP4 aircrew integrated battledress uniform while exposed to environmental conditions of 35.0°C (95°F) and 50 percent RH reached core temperatures of ~38°C (100.4°F) after 2 hours into the scenario. At that point, core temperatures diverged. One group of test subjects had a progressive increase in core temperature to ~39°C (102.2°F) at 4 hours while the others remained at about ~38°C (100.4°F). Therefore, the heat stress scenario was compensable for some test subjects, while for others it was not.

Variability in heat stress tolerance for a given scenario is related to individual differences in factors that affect the efficiency and maximum capabilities of the various heat dissipating mechanisms. Thermoregulatory efficiency is affected by adaptive (or, if training is deficient, potentially maladaptive) behavioral responses, body morphology, condition of skin and sweat glands, cardiovascular conditioning, hydration, fatigue and sleep loss, nutrition, medications, and illnesses. Factors which improve thermoregulatory efficiency decrease core and skin temperature thresholds for initiation

of thermoregulatory responses and increase the sensitivity or rate of change of these responses with respect to increases in core temperature.

An effective method for increasing thermoregulatory capacity and efficiency is heat stress acclimatization (Wenger, 1988). For scenarios consisting of comparable amounts of heat stress, clothing, and metabolic rates, heat stress acclimatization results in earlier onset and more rapid recruitment of thermoregulatory responses. Successful acclimatization results in earlier onset and increased rates of sweating, decreased heart rate, and decreased core temperature for a specific combination of environmental condition, work rate, state of hydration, and type of clothing. Heat acclimatization also results in decreased sweat sodium concentrations (Allan and Wilson, 1971). The numerous beneficial effects of heat acclimatization may effectively convert an uncompensable heat stress situation into one that is at least partially compensable.

The time required to fully acclimate to heat stress when starting from an unacclimated condition depends on the health and fitness of the individual. Those with high levels of physical fitness can acclimate rapidly (Pandolf et al., 1977). Three to five days of graded intensity exercise in hot conditions will achieve most of the beneficial acclimatization effects. Additional residual benefit continues to occur over the ensuing 1 to 2 weeks. For those whose physical fitness is less than average, acclimatization typically occurs at a more gradual pace over 10 to 14 days. Studies have demonstrated that artificial acclimatization can be as effective physiologically as acclimatizing naturally by training or doing one's usual work outdoors. Two 50-minute training sessions per day in moderately hot conditions (e.g. 100°F, 20 percent RH) for 1 to 2 weeks has been found to be sufficient for acclimatizing healthy soldiers. Activity level during acclimatization should be sufficient to elicit sweating and moderate increases in heart rate. If during acclimatization, signs of excessive heat stress occur, the activity level or environmental conditions should be reduced to be increased again more gradually over the course of several days.

Various studies have demonstrated that military chemical defense (CD) over-garments significantly impair thermoregulation in hot environmental conditions. Chemical defense ensembles invariably have high insulation values and low water vapor permeability (Gonzalez, 1988). The high thermal resistance lowers the rate of transfer of heat energy for any given temperature gradient across the thickness of the material.

Low water vapor permeability values for CD ensembles such as the BDO quantify the resistance to transport of evaporated sweat through the layers of fabric. In heat stress conditions, low water vapor permeability causes the air layer between the skin and inner surface of a CD ensemble to rapidly become saturated with sweat vapor. As the relative humidity in this air layer increases, its water vapor pressure increases and begins to approach the vapor pressure of the film of sweat on the surface of the skin. As this occurs, the net evaporation of sweat decreases and approaches zero. However,

vigorous sweating typically continues despite its inability to evaporate due to the saturated microclimate space between the skin and the inner surface of the overgarment. Unevaporated (retained) sweat accumulates in the dependent parts of the CD uniform such as boots, gloves, and CD mask. Because the unevaporated sweat has not been used for cooling, it is in a thermoregulatory sense wasted, contributing only to dehydration.

Complete evaporation of 1 liter of sweat provides 580 KCal of surface cooling. When ambient temperatures exceed body temperature, evaporation of sweat is the only effective method of dissipating body heat (Sawka and Wenger, 1988). Effective sweat evaporation rates, as determined by the rate of evaporation of sweat through the outer surface of a uniform, determines the evaporative cooling power available to the individual. It is apparent, therefore, that actual and effective sweating rates may differ considerably.

Effects of heat stress and CD protective ensembles on Army aviators

Several studies similar to this one have previously been done at USAARL. In the early 1980's Knox et al. (1983) evaluated the physiological, psychological, and flight performance effects of aviators wearing a MOPP4 ensemble while flying USAARL's UH-1 helicopter during hot summer weather. Thornton et al. (1992) completed a heat stress evaluation of a more recent Army aviator MOPP4 ensemble using USAARL's UH-60 simulator. Further description of these studies, along with enumeration of salient results and comparisons with findings from this study, are included in the Discussion section below.

Methods and procedures

Study design

This UH-60 simulator-based heat stress study utilized a 2 by 2 factorial (two main factors with two levels each), repeated measures, partially counterbalanced, and unblinded design using military helicopter pilot volunteers. The calculated minimum sample size to detect flight performance changes across the four test conditions was eight crews based on an $\alpha=0.05$, $\beta=0.20$ and variance in composite flight scores obtained from previous USAARL UH-60 simulator studies. The study was designed to evaluate the direct and interaction effects of two types of aviator uniform (MOPP0 ABDU vs. the current encumbered MOPP4 aviator ensemble) and two cockpit thermal conditions (cool vs. hot) on flight performance and physiologic responses in the environmentally controlled USAARL UH-60 simulator.

Four different test conditions were required per test subject (cool and hot while wearing both the ABDU and encumbered MOPP4 uniforms). If the two different flight uniforms had only been tested in the hot condition, it would not have been possible to

determine whether differences in flight performance and physiological parameters were due entirely to heat stress, entirely to the type of ensemble, or to a combination of these two factors.

Counterbalancing the order of the conditions within the test subject group was done to help control for order and carry-over effects. Intrasubject counterbalancing did not apply for this study because all study volunteers were exposed to each test condition only once. Counterbalancing can be categorized as complete, incomplete, and randomized. Since we had fewer volunteer aviators than possible testing sequences, it was necessary to use incomplete counterbalancing (Christensen, 1985). The volunteer aviators were assigned to the four different sequences in order of arrival with repetition of the sequences in a cyclic order until all test subjects had been assigned to a testing sequence (table 1).

Environmental conditions

The cool simulator condition consisted of a dry bulb temperature (T_{db}) of 70°F (21.1°C) and 50 percent RH. The hot condition utilized a T_{db} of 100°F(37.8°C) and 50 percent RH. The WBGT values for the two conditions in the simulator included the effects of radiant energy emitted by three 250 Watt heat lamp bulbs situated in the roof above each pilot's helmet (see last page of appendix H for a graph of the spectral output). Consistent with the Thorton (1992) study, the rheostats for the overhead bank of heat lamps in the simulator were set at 50 percent. Conditions in the environmental chamber during the 20-minute simulated preflights had the same temperature settings as the simulator but lower relative humidity (20 percent). It was not feasible to install heat lamps in the environmental chamber. Humidity in the UH-60 simulator was set at a higher value to emulate the increase in humidity that occurs when doors and windows are closed in an actual UH-60 operating in hot-dry desert conditions.

Flight uniforms

Table 2, which lists the components of the two aviator ensembles utilized in this study, is followed by figure 1, which depicts test subjects wearing the encumbered MOPP4 flight uniform components. Table 3 provides the average total and component weights for each of the two tested aviator uniforms.

Table 1.
Incomplete Counterbalancing of Test Conditions

	Test Session #1	Test Session #2	Test Session #3	Test Session #4
TEST SUBJECT #	Uniform Environment	Uniform Environment	Uniform Environment	Uniform Environment
1 & 2	ABDU-Mod	MOPP4-Mod	MOPP4-Hot	ABDU-Hot
3 & 4	MOPP4-Mod	ABDU-Hot	ABDU-Mod	MOPP4-Hot
5	ABDU-Hot	MOPP4-Hot	MOPP4-Mod	ABDU-Mod
6 & 7	ABDU-Mod	MOPP4-Mod	MOPP4-Hot	ABDU-Hot
8 & 9	MOPP4-Hot	ABDU-Mod	ABDU-Hot	MOPP4-Mod
10 & 11	MOPP4-Mod	ABDU-Hot	ABDU-Mod	MOPP4-Hot
12 & 13	ABDU-Hot	MOPP4-Hot	MOPP4-Mod	ABDU-Mod
14 & 15	MOPP4-Hot	ABDU-Mod	ABDU-Hot	MOPP4-Mod
16 & 17	ABDU-Mod	MOPP4-Mod	MOPP4-Hot	ABDU-Hot

<u>Table 2.</u>
Encumbered MOPP4 heat stress study aviator ensembles.

ITEMS	ABDU	Encumbered MOPP4
HGU-56P	x	x
ABDU	x	x
Combat boots	x	x
Flight gloves (summer light)	x	x
Kneeboard	x	x
SARVIP vest with mod	x	x
SARVIP 0.50 cal armor		x
SARVIP packs		x
M43A1 CB Mask		x
BDO		x
PRC-112A survival radio		x
LPU-21 a/P water wings		x
LRU-18P raft		x
SRU-37/P container (raft)		x
HEED		x

The following is a description of the SARVIP:

> The SARVIP ... consists of a Rashel knit NOMEX, fire resistant fabric vest with 12 pockets, 10 outer pockets and 2 inner pockets. The pockets hold all survival, signal, and communications components. The vest includes a rescue lift strap, two leg straps, and a chest strap. Additionally, the chest strap provides a means for attaching life preserver units (LPUs). The vest has two small "D" rings attached to the front and sides for attaching the protective mask and blower.
>
> The .50-caliber armor insert is made of laminated ceramic/fiberglass and has a foam pad backing. The carrier for the insert is made of NOMEX and seven layer of KEVLAR, and it has a quick-release strap at the bottom for emergency release of the plate. The packets have vacuum-packed, Nylon-Polyethylene pouches and hold all basic individual and medical survival items (Ryan, 1993).

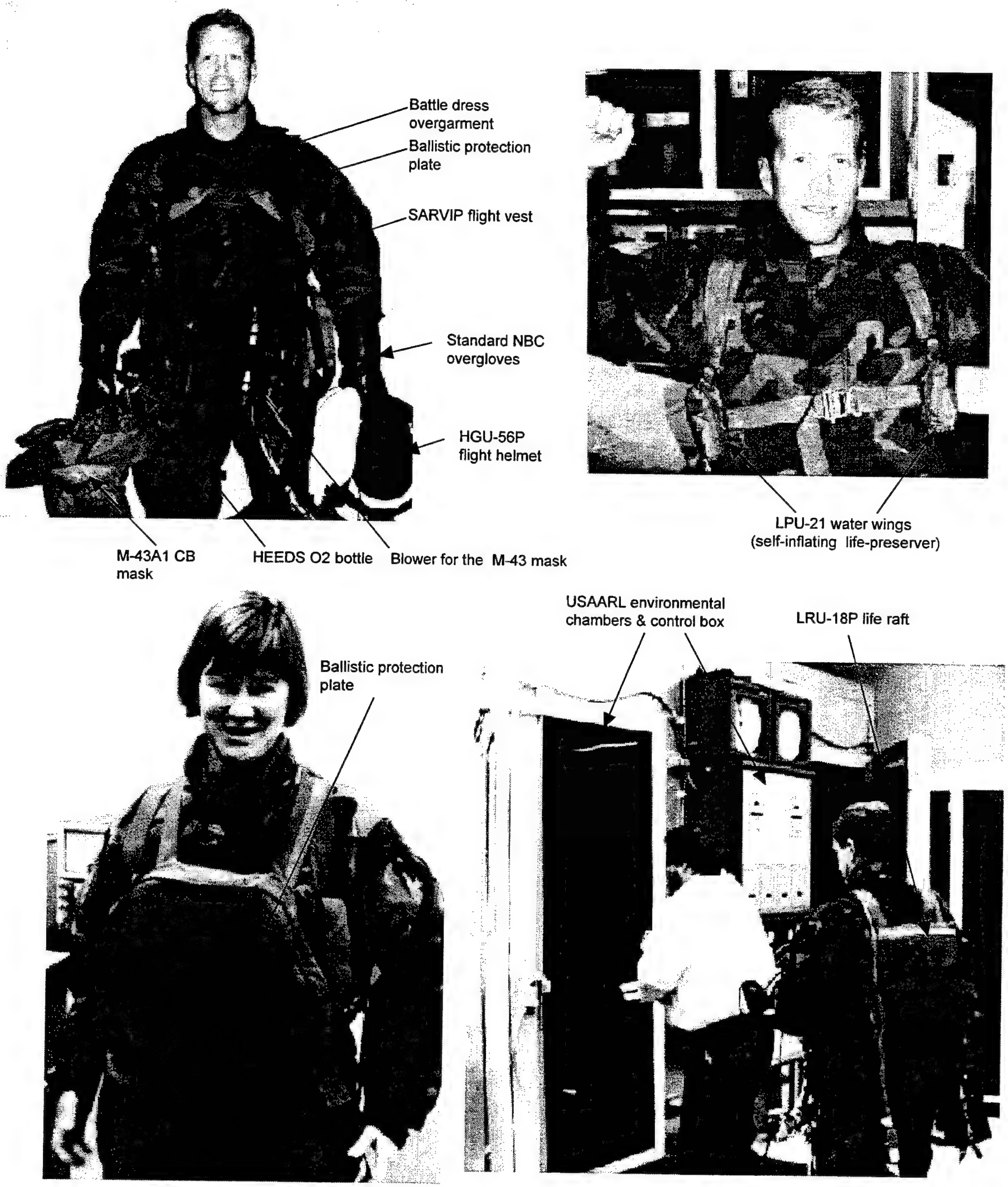


Figure 1. Photos of the aviator uniform components.

Table 3.
Current Flight Uniform Component Weights

MASKS	LB.	KG
medium	3.03	1.37
	3.29	1.49
	3.21	1.45
	3.28	1.49
large	2.97	1.34
	3.24	1.47
x-large	3.01	1.36
AVERAGE	**3.14**	**1.43**
BLOWER(w/filters)		
	5.98	2.71
	6.04	2.74
AVERAGE	**6.01**	**2.73**
NBC GLOVES		
small	0.21	0.09
medium	0.24	0.11
	0.23	0.10
	0.22	0.10
large	0.23	0.11
x-large	0.25	0.11
AVERAGE	**0.23**	**0.10**
NBC BOOTS		
size 12	3.36	1.52
size 10	3.04	1.38
size 11	3.08	1.40
AVERAGE	**3.16**	**1.43**
NBC PANTS		
small	2.59	1.17
large	2.77	1.26
	2.89	1.31
x-large	3.16	1.43
AVERAGE	**2.85**	**1.29**
NBC SHIRTS		
small	2.48	1.12
large	2.93	1.33
	2.66	1.20
x-large	2.83	1.28
AVERAGE	**2.72**	**1.23**
***ABDU SHIRTS**		
small/reg	0.99	0.45
	0.99	0.45
small/long	1.02	0.46
	1.02	0.46
med/reg	1.07	0.48
	1.04	0.47
med/long		
large/reg	1.10	0.50
	1.10	0.50
large/long	1.13	0.51
	1.14	0.52
AVERAGE	**1.06**	**0.48**

LIFE RAFT	LB.	KG
one-size	4.94	2.24
	4.58	2.07
AVERAGE	**4.76**	**2.16**
WATER-WINGS		
one-size	3.09	1.40
	3.03	1.37
AVERAGE	**3.06**	**1.39**
BALLISTIC PROTECTION PLATE		
medium	10.88	4.93
	12.15	5.51
	12.09	5.48
AVERAGE	**11.71**	**5.31**
***SARVIP**		
medium	8.22	3.73
x-large	7.86	3.56
	7.92	3.73
AVERAGE	**8.00**	**3.67**
HEEDS O2 BOTTLE		
one-size	1.79	0.81
	1.76	0.80
AVERAGE	**1.77**	**0.80**
***FLIGHT GLOVES**		
size 7	0.18	0.08
size 8	0.17	0.08
size 11	0.21	0.09
AVERAGE	**0.19**	**0.08**
***BOOTS**		
	3.91	1.77
	4.07	1.85
AVERAGE	**3.99**	**1.81**
***HELMET**		
small		
medium		
large	3.28	1.49
x-large	3.37	1.53
AVERAGE	**3.32**	**1.51**
***ABDU PANTS**		
small/reg	1.09	0.49
	1.09	0.49
small/long	1.13	0.51
	1.13	0.51
med/reg	1.15	0.52
med/long	1.14	0.52
large/reg	1.18	0.53
	1.17	0.53
large/long	1.21	0.55
	1.21	0.55
AVERAGE	**1.15**	**0.52**

	LB.	KG
MOPP4 FULLY ENCUMBERED AVERAGE WEIGHT	**57.09**	**25.94**
***STANDARD FLIGHT AVERAGE WEIGHT**	**17.70**	**8.07**

The M43 CD mask consists of a bromobutyl rubber facepiece with an attached butyl rubber hood that drapes over the neck and shoulders. The mask is pressurized by a 12-volt non rechargeable lithium battery-powered blower assembly. The blower pushes ambient air through two standard round CD canister filters and into a single air hose that inserts into the left frontal aspect of the mask. The slightly pressurized air entering the mask is partially directed towards the eyepieces to prevent vapor condensation and also over the forehead to provide some cooling. The mask has an integrated microphone and drinking tube.

UH-60 simulator flight missions

The two missions used in each test session consisted of a 2-hour air assault (AA) scenario followed by a 10 minute simulated hot-refuel break, then a 2-hour medical evacuation (MEDEVAC) scenario. These mission scenarios were selected because they were representative of the mission types for the UH-60 helicopter (USAAC, 1989). There were a total of eight different flight maneuvers or modes: hover (HOV), hover turn (HOVT), right standard rate turn (RSRT), left descending turn (LDT), straight and level (SL), left climbing turn (LCT), contour, and nap-of-the-earth (NOE).

The hover maneuver required the pilot to bring the aircraft to a 10-foot hover on a heading of 360° and hold there for 60 seconds. Upon completion of the hover, the pilot performed a hover turn which required a 360° turn in 60 seconds while maintaining a 10-foot altitude. There were four HOV and HOVT maneuvers in the first 2-hour sortie and three in the second 2-hour sortie. After each HOV and HOVT, the pilots flew NOE or contour to designated control points. During the contour and NOE segments for both the air assault and MEDEVAC scenarios, the pilot and copilot were allowed to transfer flight control. Every 30 minutes, at the end of specific contour or NOE flight segments, inadvertent meteorologic conditions (IMC) were generated by the simulator operator. The right seat pilot then took the flight controls and ascended to 2000 feet to fly a 10 minute set of standard maneuvers (SL, RSRT, LCT, SL, LDT, SL). While the right seat pilot was flying the set of standard maneuvers, the left seat pilot was performing a 10-minute performance test on a laptop computer. At the end of each set of standard maneuvers, the pilot descended out of IMC conditions to resume contour or NOE flight between control points. Flight performance and computer-based test results, as well as greater detail regarding the flight profiles, are presented in a separate technical report.

Physiological

Measurement of heart rate

Heart rates were recorded using a three lead system with Ver-Med * electrodes. The electrodes were positioned to maximize the R-wave tracing since the leads were connected to a battery powered R-wave counter *. When necessary, permission was requested to shave a small amount of hair over the preferred electrode locations so that sufficient skin-to-electrode contact was obtained to maintain a reliable signal for heart rate determination.

We noted that the R-wave amplitude in some volunteers varied considerably with changes in posture and depth of breathing. Typically, the aviator volunteers were sitting up straight when the ECG leads were initially applied so that we were usually able to obtain a tall R-wave. Often, however, after they had been flying the simulator for variable lengths of time, we would lose R-wave capture and the backup ECG monitor would indicate that the QRS complex was considerably reduced in amplitude. We attributed such changes in QRS morphology to hunching over the controls and a more shallow respiratory pattern while the volunteers were concentrating on flying tasks in the simulator.

Measurement of body core temperature

Two temperature sensor systems were used in order to compare alternative methods of obtaining core temperature measurements. The primary core temperature measurement method was a standard rectal temperature thermistor (figure 2). The second method utilized an ingestible telemetry pill with harness antennae connected to an ambulatory data recorder (figure 4). The core temperature pill and rectal temperature thermistor data were compared with respect to accuracy, stability, and susceptibility to stray electromagnetic interference within the simulator.

We utilized YSI 401 * rectal thermistors. Prior to use, the temperature sensors were calibrated in a stirred water bath with a precision calibrating thermometer (figure 3).

As a brief review, thermistors are semiconductor temperature sensors. These temperature sensing semiconductors typically contain heavy metals such as cobalt or manganese and have a resistance that is an exponential function of temperature: $R = A * \exp(b/T)$, where A and b are constants and T is in °C (Carter, 1986). Linearization of the resistance with respect to temperature is usually achieved by making the thermistor part of a Wheatstone Bridge resistance circuit. Since thermistors can be damaged by excessive heat, they are usually cold rather than heat sterilized.

---

* See list of manufacturers in Appendix H

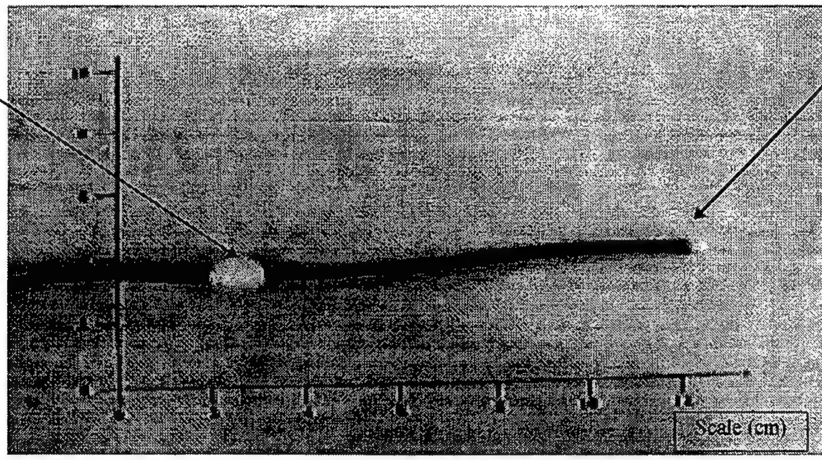


Figure 2. Rectal thermistor.

Figure 3. Thermistor calibration.

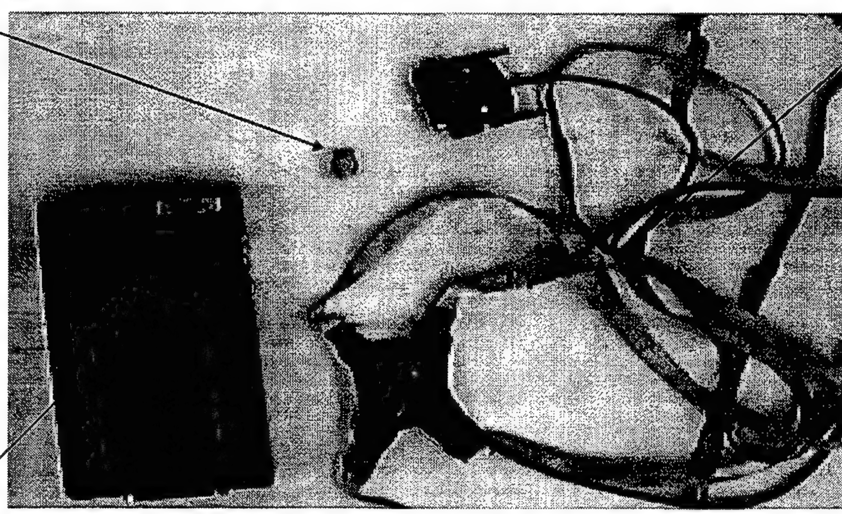


Figure 4. CorTemp system.

The rectal thermistor has proven to be quite safe when used by test subjects who are healthy and do not have inflammatory bowel or rectosigmoid diseases or strictures. Prospective volunteers were medically screened to detect criteria precluding use of the rectal thermistor, such as a history of abdominal surgery, recent rectal bleeding, rectal fissures, painful hemorrhoids, history of inflammatory bowel disease, or other rectosigmoid problems. Other exclusionary criteria relating to the use of rectal thermistors include diagnoses of AIDS, hepatitis B, or recent hazardous infectious diarrheal diseases. None of the volunteers in this research study had exclusionary conditions.

Each rectal thermistor was tagged with the test subject's number. Between use they were maintained in a separate plastic tube of Mint-A-Dish Disinfectant *. Prior to each study session, the rectal thermistor was removed from the disinfectant soak, washed off under a water faucet, and dried with a paper towel. Each thermistor was checked for rough edges or signs of excessive bending and wear. We had one rectal thermistor that began giving erroneous temperature readings prior to a test session. Inspection revealed a break in the plastic, so it was discarded and replaced with another pre calibrated thermistor.

A disposable CorTemp* ingestible core temperature pill was also used to monitor test subjects' core temperature. A copy of the product brochure is included in appendix H. The temperature pill was about the size of a large multivitamin capsule. It had a smooth, but tough, silicon plastic exterior to facilitate swallowing it. The core temperature pill emitted a weak radio signal that was received by a flexible antennae harness that was strapped around the chest. The pill's effective range (about 10-12 inches) was limited by the pickup capability of the antennae and data recorder. The pill could transmit for up to 200 hours, however, transit time through the gastrointestinal tract superseded battery life.

The receiver antennae was worn over a t-shirt, and its output attached to a portable data recorder. The data recorder displayed the transmitted core temperature for real-time temperature monitoring. Since unfiltered core temperature pill data was occasionally quite erratic with unrealistic discontinuities, rectal thermistor readings were used for assessing compliance with the core temperature limits (Bruckart et al., 1992).

Stephenson et al., (1992) found that core temperature data obtained with the CorTemp* pill system was similar in responsivity to esophageal core temperature readings. That is, the core temperature pill reacted more rapidly to changes in work intensity than the rectal thermistor. However, since test subject metabolic rates in the simulator did not vary much, the difference in responsiveness between core profiles obtained with rectal versus ingested pill was not as apparent as it was in other studies using intermittent exercise in hot conditions. The core temperature pill data from Stephenson were generally more variable from measurement to measurement due to frequent signal transmission and reception problems, electromagnetic interference, and

natural differences in temperatures throughout the intestinal tract. For example, hepatic temperatures can be 1-2°F higher than other intra-abdominal viscera.

Contraindications to use of the core temperature pill included: body weight less than 80 pounds, obstructive diseases of the gastrointestinal (GI) tract, inflammatory bowel disease, history of intra-abdominal surgery, impaired gag reflex, esophageal disorders, or hypomotility of the GI tract (HTI, 1991). Additionally, while a core temperature telemetry pill is within the body, the individual should not undergo magnetic resonance imaging (MRI) because the strong radio frequency pulses used during MRI theoretically could disrupt and/or overheat the pill's small silver-oxide battery which could cause irritation and chemical burns of the intestinal tract if it were to rupture. Elemental silver is also toxic if absorbed in significant quantities.

Measurement of skin temperature

Skin temperature was measured with YSI 400 series * surface thermistors which were held in position with collodion. These thermistors were placed over the anterior chest (T_{chest}), upper arm (T_{arm}), outer thigh (T_{thigh}), and outer calf (T_{calf}). A weighted mean skin temperature(T_{sk}) was calculated using the following formula (Ramanthan, 1964):

$$T_{sk} = 0.3\ T_{chest} + 0.3\ T_{arm} + 0.2\ T_{thigh} + 0.2\ T_{calf}$$

These sensors were applied to the appropriate locations on the skin prior to each study session. The collodion affixed the sensors securely to the skin to prevent separation caused by sweating. The skin was inspected daily to avoid placing these sensors on any lesions and to detect any evidence of sensitization to metallic ions from the sensors due to immersion in sweat. After each use, the sensors were cleaned and allowed to air dry.

Measurement of dehydration

Pre- and post-study session, total undressed and dressed weights were obtained in order to determine the amount of cumulative dehydration and sweating that occurred during each test session.

At the beginning of each test session, the volunteer aviators first urinated and then obtained a nude weight. They self-inserted the rectal thermistor. A technician then applied the skin temperature and ECG sensors. Next, the test subjects donned the appropriate ensemble, and a dressed weight was obtained. Before and after each test session, fluids and snack foods were individually weighed. Voided urine was also collected and weights recorded. At the end of each day's test session, a fully clothed weight was again obtained. The ensemble was then removed and a post-session nude weight obtained. Body weight and fluid data were recorded on a form (appendix F) which facilitated subsequent analysis.

Dehydration was calculated by using the term: $100*[(weight_{sweat\ loss} + weight_{urine\ output} - weight_{water}) / weight_{initial\ nude}]$. Sweat loss estimate was obtained from the term: $(weight_{initial\ nude} - weight_{post\ nude}) + (weight_{water} + weight_{food} - weight_{urine})$. Total sweat loss minus evaporated sweat permitted assessment of the amount of sweat retained in the ensemble. For each test session, we were able to determine total amounts of sweat, sweat rates, amount of sweat evaporated, and amount retained in the uniform.

Psychological

Mood and symptoms

A twelve-question mood and symptoms questionnaire developed for this study was administered before and approximately every 30 minutes after the volunteer pilots began the treadmill session in the environmental chamber (appendix E). Using a 0-10 Likert-type scale (0=none, 10=maximum), the volunteers assessed their sensation of: headache, nausea, stress, anger, depression, energy, heat stress, thirst, workload, boredom, dizziness, and visual difficulty. Hot spot locations and intensities were also reported.

Profile of mood states (POMS)

The POMS was also used to measure changes in various components of the volunteers' mood. The POMS is a list of 65 questions utilizing a 5-point adjective rating scale. It provides a statistically derived factor inventory as a method of identifying and assessing transient and fluctuating affective states (McNair, Lorr, and Droppleman, 1981). The POMS scoring process produces one total mood disturbance score and subscores for six mood categories (tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment). The POMS was administered in the test subject preparation room prior to the simulated preflight (pre-test) and again in the recovery/cool-down room immediately after completing each simulator session.

Task load index (TLX)

The NASA TLX, developed by the Human Performance Research Group at the NASA Ames Research Center (Hart and Staveland, 1988), was administered to the right-seat pilot at the completion of each set of standard maneuvers and to the left-seat pilot immediately after completing each 10-minute Multi Attribute Task Battery (MATB) performance test. Using a 0-20 Likert-type scale, the volunteers provided their assessment of the following sensations: mental demand, physical demand, temporal demand, own performance, effort, and frustration.

Sequence of events in the study

On their first day, volunteers received a detailed briefing regarding the study, read and signed the informed consent, and were medically screened for any evidence of illness or excess risk. Female volunteers were negative on a serum pregnancy test obtained as part of the medical evaluation. The aviator volunteers participated for 2 consecutive weeks. The first week was for uniform and helmet fitting, simulator and MATB training, and heat stress acclimatization in the environmental chamber. During the second week (test week), the aviators completed four test sessions, one session per day for 4 consecutive days (Mon-Thurs).

Ambient conditions in the environmental chamber during acclimatization were 100°F and 20 percent RH. The test subjects walked on a treadmill at 3 mph and 0 percent grade for two 30-minute intervals separated by a 10 minute rest break. After most acclimatization periods in the environmental chamber, the test subjects then entered the UH-60 flight simulator for a 2-hour training flight with ambient conditions in the cabin increased daily from 90°F and 50 percent RH to 100°F and 50 percent RH. These simulator sessions provided additional acclimatization as well as familiarization with the two flight scenarios, the MATB computerized performance test, and questionnaires.

During their second week, test subjects arrived each day at approximately 0700 hours, were assisted in the application of physiological sensors (rectal thermistor, core temperature pill, skin temperature sensors, and ECG leads), and donned the designated flight ensemble for that day (figure 5). The volunteers then entered the environmental chamber where they walked on treadmills at a 3 mph pace with 0 percent grade for 20 minutes to simulate the metabolic expenditure of a preflight inspection of a UH-60. After completing the 20-minute simulated preflight inspection, the two volunteer aviators walked a short distance down several short corridors to the USAARL UH-60 simulator. Pre- and posttest weights and fluid intake and output were measured and core temperature and heart rate were monitored every 10 minutes with adherence to physiological limits as approved in the research protocol (core temperature limit of 102.56°F, or 39.2°C, and heart rate not to exceed 90 percent of age adjusted predicted maximum).

Each simulator flight session during the test week consisted of two 2-hour scenarios (air assault and medical evacuation, respectively) with an intervening 10-minute simulated hot refueling break. Every 30 minutes during the simulator session, the right seat pilot encountered IMC conditions and flew a 10-minute set of standard flight maneuvers. During the simulator flights, the data acquisition systems collected flight performance and physiological data. When subjective or objective indicators suggested that test subject tolerance limits were about to be reached, the volunteer pilots were instructed to make a simulated landing and one or both test subject(s) were assisted out of the simulator.

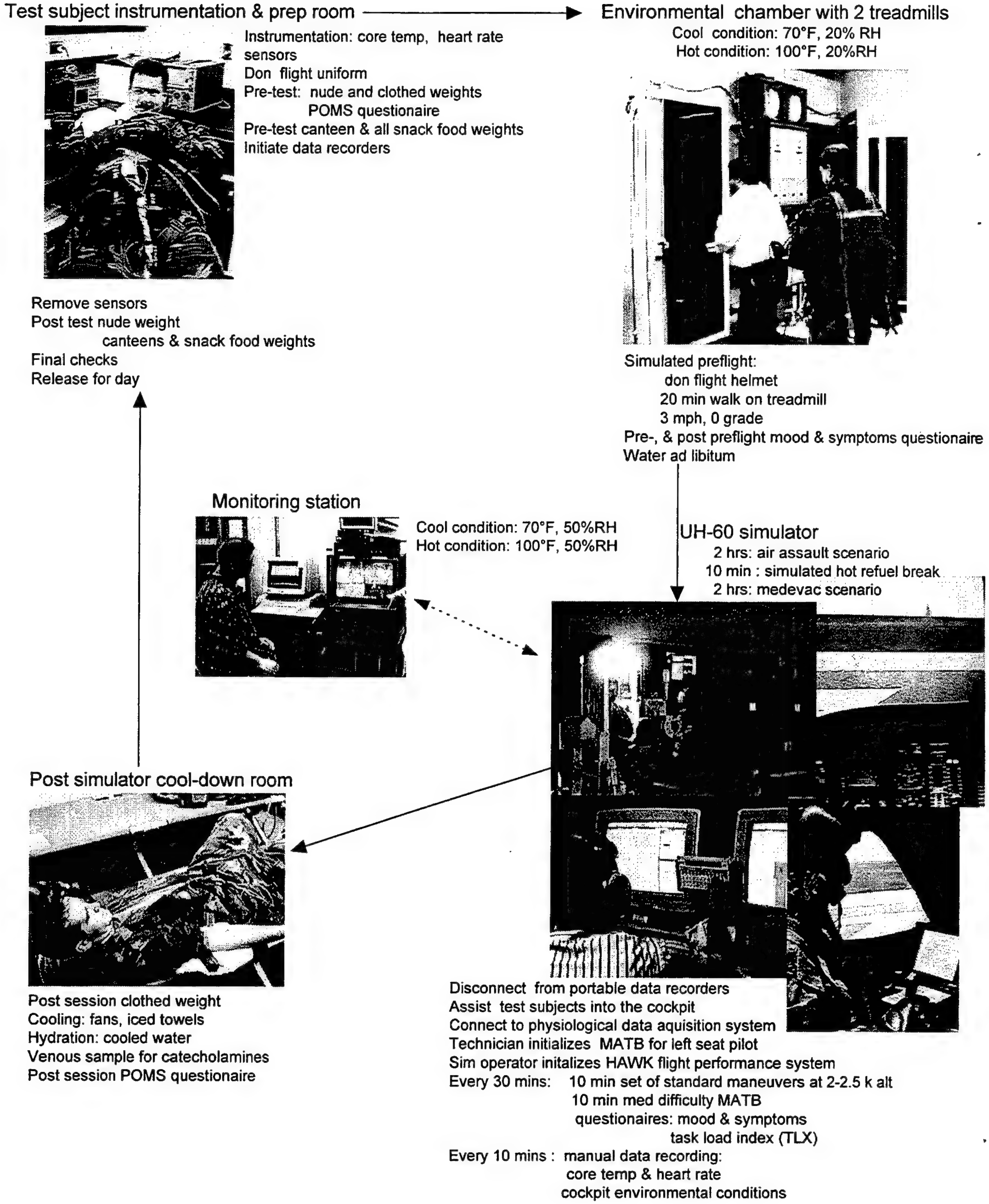


Figure 5. Heat stress study process.

While the right seat pilot was flying the set of standard maneuvers, the left seat pilot was simultaneously using a stowable laptop computer and joystick to take a 10-minute, moderate difficulty level, MATB performance test. The mood and symptoms questionnaire was also administered approximately every 30 minutes during the entire test session.

Results

This section provides primarily a general overview of main results supported with graphical presentations of summary statistics. Tables of additional statistics are included in appendix A, and the extensive results of multivariate hypothesis testing procedures, such as multiple analysis of variance, analysis of variance, and multiple correlations are provided in appendix B.

The sample size (or "n") for the various results differed according to the particular variables evaluated. For example, core temperature, heart rate, and fluid balance data were obtained for all test subjects. However, fluid balance data for the first four test subjects were identified as incorrect due to specific problems which were subsequently corrected. The defective data, therefore, were excluded from the weight and fluid balance results. Flight performance and MATB data were obtained only on odd and even numbered test subjects respectively.

Multivariate analysis of variance (MANOVA) was performed on sets of related physiological and questionnaire variables and the main factors (environmental conditions and type of ensemble). MANOVA was used to determine whether there was an overall effect of its conditions on mean responses. Repeated measures analysis of variance (ANOVA) was the primary statistical procedure used to determine whether means for response variables were significantly different across the two levels for each of the main factors.

For ease of interpretation, all ANOVA results tables list means for each variable across the test conditions and the resulting F and p statistics for both main effects (environmental temperature setting and type of flight uniform) and interaction effect between the levels of the main factors. The customary $p \leq 0.05$ criteria served as the decision threshold for rejecting null hypotheses that differences in means were due exclusively to chance or uncontrolled random effects.

In the following enumeration and discussion of findings, the associated F and p values, along with corresponding degrees of freedom for MANOVA and ANOVA results, are not enumerated because they are provided in the appropriate tables of appendix B.

Since there were only two levels within the two main factors, ANOVA post-hoc testing was not necessary. The means and p-values in the ANOVA results tables are used in conjunction with each other to determine the magnitude and direction of

differences in mean responses for variables across the different levels of the two factors. Significance for only the environmental temperature factor indicates that differences in means were only associated with differences in environmental temperature but not the different flight uniforms. Likewise significance for a variable for only the uniform factor indicates that differences in mean responses were only associated with type of uniform but not with the different temperature conditions. Significance for interaction between temperature and uniform indicates that the relative magnitude of the responses for the temperature conditions were significantly different, or in some cases, even reversed across the two tested aviator uniforms.

Test subjects

Fourteen aviators between the ages of 27 and 50 (mean 35.6 years) participated in this study. No volunteer had an exclusionary medical condition. Each of the 14 completed at least 1 week of actual testing. Three test subjects volunteered for an additional test week. Therefore, there were 14 distinct test subjects, but 17 test subject numbers. Two of the volunteer aviators (14.2 percent) were female pilots. Four aviators (28.6 percent) had previously participated in other USAARL studies. There were 3 officers and 11 warrant officers. Four (28.6 percent) volunteers were from the Army National Guard, the remainder (77.4 percent) were from various CONUS and OCONUS active duty Army aviation units.

Ten (71.4 percent) of the aviators were UH-60 rated; the remainder were rated in various other helicopters. Average total career flight time was 1453 (320-2800) hours with an average of 452 (0-1800) total hours flying UH-60s and an average of 69 (0-300) total hours in UH-60 simulators.

Test subject average height and weight was 70 inches and 170 pounds. Performance results for their most recent PT test included: average score of 261 (209-300) with an average of 55 pushups, 63 situps, and 17:52 for the 2-mile run. The average self-rated effort for their most recent PT test was 92 percent of perceived maximum possible effort. These data indicated that the test subjects, as a group, were in good physical condition.

Average number of hours of NBC training over the preceding 1 and 5 years was 0.64 (0-3) and 8 (0-52) hours, respectively. They also had an average of 1.28 (0-6) hours of heat illness prevention training over the preceding 2 years. For illustrated details see figure 6.

Environmental conditions

Mean simulator cockpit temperatures and humidity across the four test conditions are displayed in figure 7. Those statistics confirm that there were no significant differences in measured versus target values for either the temperature or humidity (70°F, 50 percent RH and 100°F, 50 percent RH) across the two different flight uniforms (MOPP0

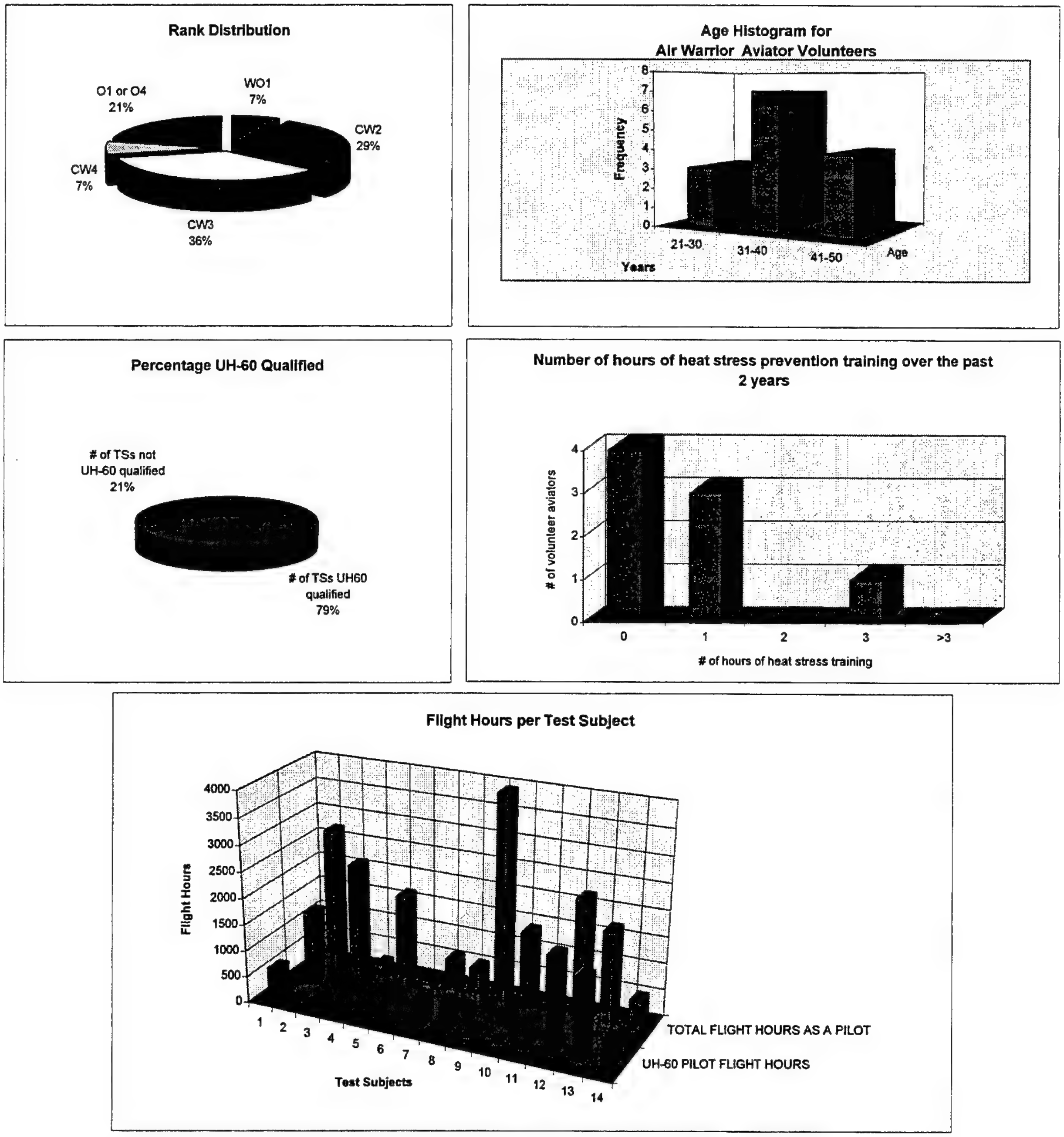


Figure 6. Demographics charts.

ABDU and encumbered MOPP4 over ABDU). Measured cockpit WBGT was 70°F (21.1°C) for the cool condition and 90°F (32.2°C) for the hot condition. To confirm that the actual environmental conditions were as specified, ANOVA was performed on mean (to each test session) cockpit temperatures and humidity. These were the target values, therefore, providing evidence of close control of the environmental conditions during the study.

Physiological results

Endurance

None of the volunteer aviators were able to complete even the first of the two 2-hour sorties while fully encumbered in the 100°F, 50 percent RH condition. However, in the other three conditions, all the aviators completed the entire two sortie missions. The average endurance times in the encumbered MOPP4 - hot condition was 107 (152-40) minutes whereas in the other three conditions it was 309 (347-288) minutes. The aviators in the MOPP0 cool, MOPP0 hot, and MOPP4 cool could have continued; however, the study was not designed to determine maximum possible endurance in those conditions (figure 8).

Heart rate

With the aviators in the encumbered MOPP4 over ABDU ensemble in the hot condition, heart rate rose rapidly to an average maximum of 142 (170-119) beats per minute (bpm) during the simulated preflight on the treadmill and then remained elevated with an average heart rate of 133 (164-102) bpm and average maximum of 143 (170-119) bpm during the simulator session. The heart rate in the other hot condition (MOPP0 ABDU) rose to moderately high levels with an average maximum of 100 (122-73) bpm during the simulated preflight inspection on the treadmill, reduced after the treadmill session was completed, but then increased again in the simulator to an average maximum of 111 (135-91) bpm (see figures 9 and 10).

During the ABDU MOPP0 70°F condition, the average maximum heart rate during the simulated preflight was 107 (136-91) bpm and during the simulator sorties 88 (105-73) bpm. Likewise, for the encumbered MOPP4 70°F condition, the average maximum heart rate during the simulated preflight was 127 (169-84) bpm and during the simulator sorties 110 (156-78) bpm.

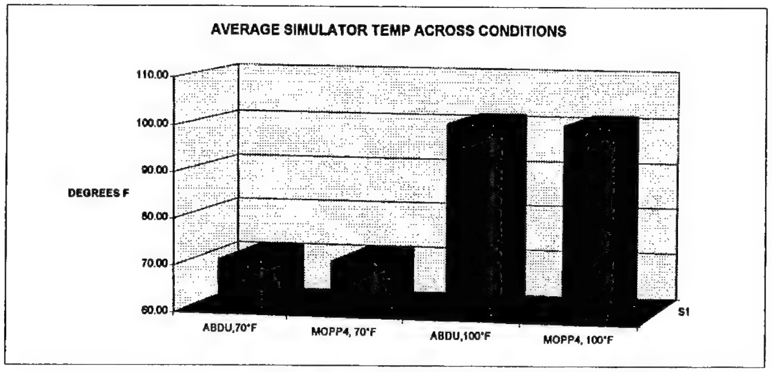
As indicated in appendix B, preflight, simulator flight, and overall average heart rates showed significant main effects for temperature and type of flight uniform. Mean heart rates while in the simulator were substantially higher for the hot and encumbered MOPP4 conditions. There was also an interaction effect between the hot condition and the encumbered MOPP4 ensemble on heart rate while the volunteer aviators were in the simulator but not during the simulated preflight. This interaction was due to a much larger increase in heart rate for the hot versus cool condition in the encumbered

REPEATED MEASURES ANOVA RESULTS FOR SIMULATOR TEMPERATURE

		MEAN TEMPERATURE BY CONDITION				MAIN EFFECTS: TEMPERATURE		MAIN EFFECTS: UNIFORM		INTERACTION TEMPERATURE X UNIFORM	
EVENT	NUM TSs	ABDU,70°F	MOPP4, 70°F	ABDU,100°F	MOPP4, 100°F	F VALUE(1,8)	P VALUE	F VALUE(1,8)	P VALUE	F VALUE(1,8)	P VALUE
SIMULATOR AVERAGE	9	70.60	70.79	100.91	100.88	9488.93	0.0000	0.10	0.7605	0.20	0.6661

REPEATED MEASURES ANOVA RESULTS FOR SIMULATOR HUMIDITY

		MEAN RELATIVE HUMIDITY BY CONDITION				MAIN EFFECTS: HUMIDITY		MAIN EFFECTS: UNIFORM		INTERACTION TEMPERATURE X UNIFORM	
EVENT	NUM TSs	ABDU,70°F	MOPP4, 70°F	ABDU,100°F	MOPP4, 100°F	F VALUE(1,8)	P VALUE	F VALUE(1,8)	P VALUE	F VALUE(1,8)	P VALUE
SIMULATOR AVERAGE	9	47.66	49.05	48.66	49.54	0.50	0.5009	2.24	0.1727	0.08	0.7821



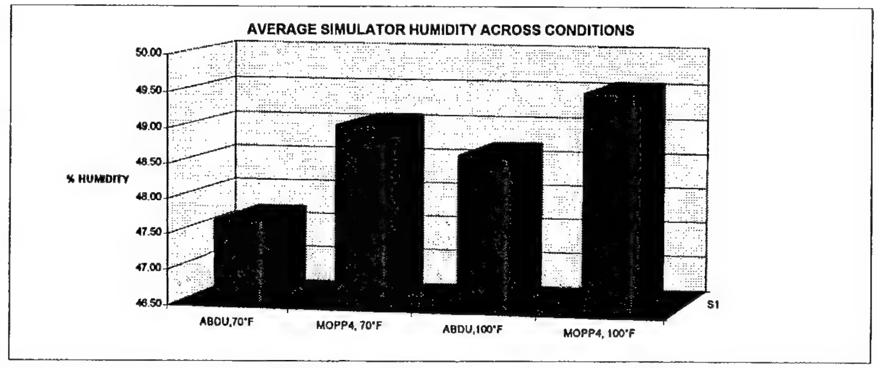
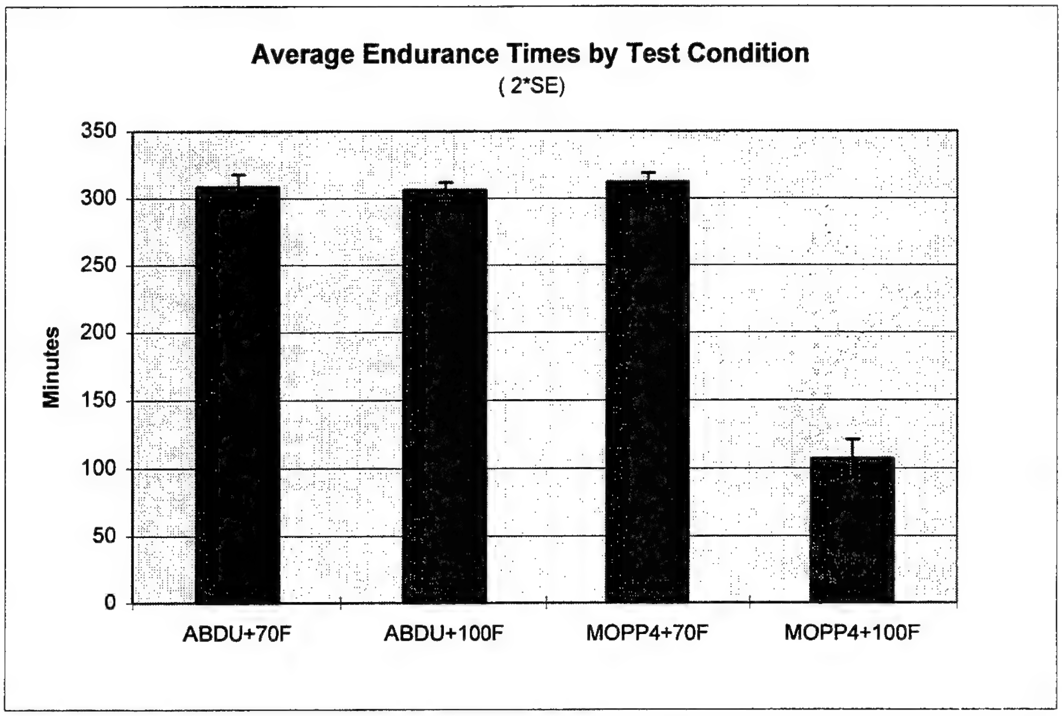


Figure 7. ANOVA results for UH-60 simulator temperatures and relative humidity.



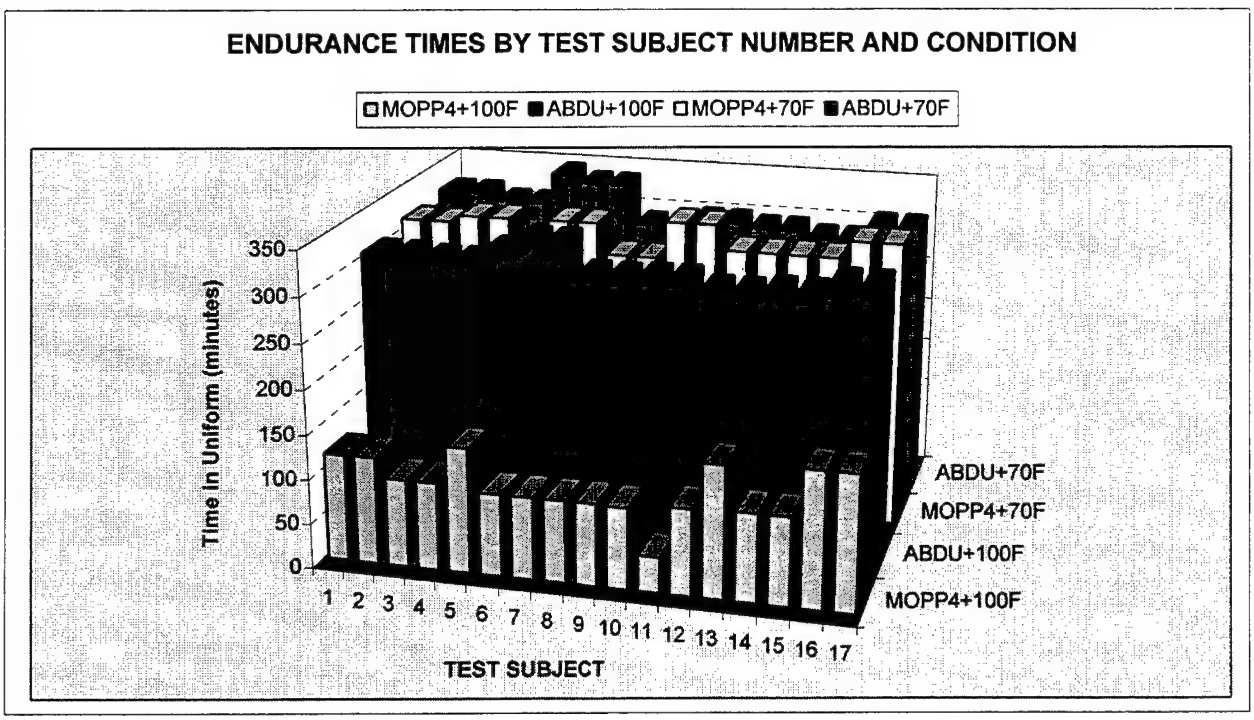


Figure 8. Endurance time profiles.

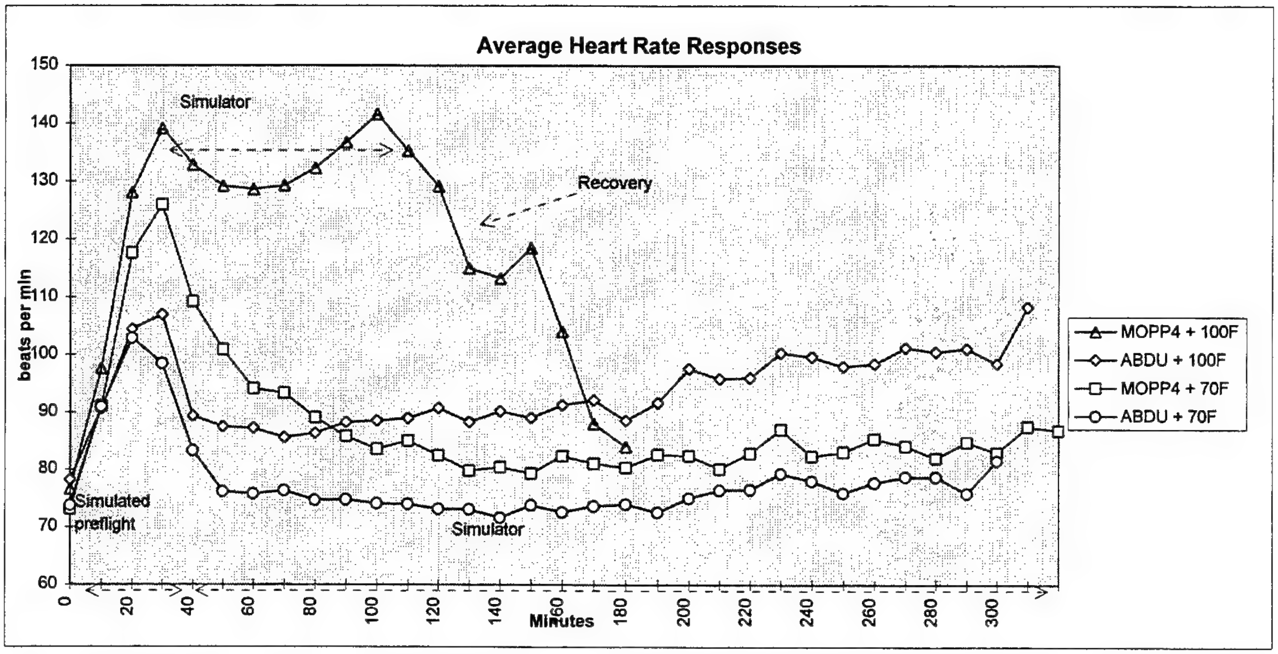


Figure 9. Average heart rate profiles.

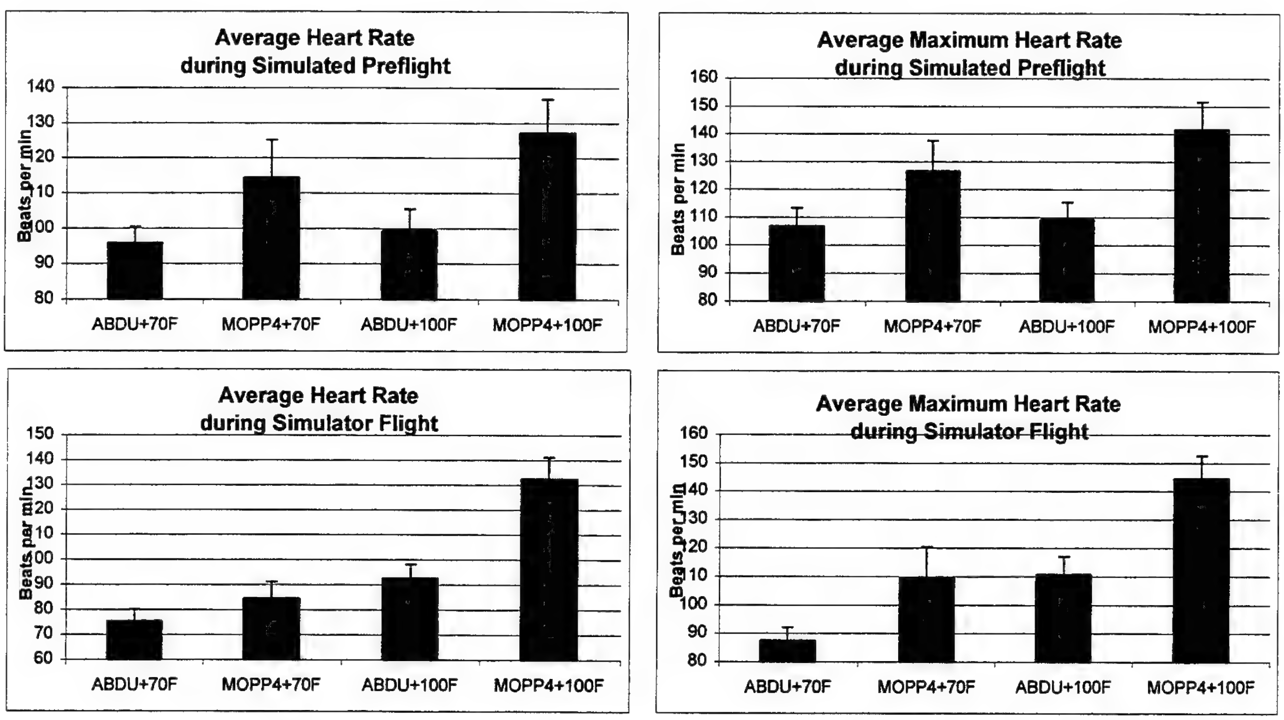


Figure 10. Average and maximum heart rate charts.

MOPP4 ensemble compared to a lesser heart rate increase for the hot versus cool condition with the aviators wearing ABDUs.

Figure 11 shows average rate of heart rate changes with respect to time for the four different test conditions. The most rapid increase in heart rate for all the test conditions occurred during the simulated preflight walk on the treadmill in the environmental chamber. Heart rate decreased rapidly after getting off the treadmill. Heart rate during the simulator sessions did not fluctuate much. There was a small amplitude oscillation about baseline heart rates while the volunteer aviators were in the simulator. Comparison of the oscillatory pattern with the flight profiles indicates that heart rate increased above baseline during NOE and contour flight segments and decreased slightly while flying the set of standard maneuvers or taking the MATB computer performance test.

Core temperature

Figures 12 and 13 illustrate the rapid core temperature increase (mean increase of 0.73°F/hr) in the hot condition with the pilots wearing the encumbered MOPP4 ensemble. In that condition, none of the pilots were able to complete the first 2-hour mission (air assault profile) due to voluntary withdrawal (n=1) or one of the crew reaching the core temperature limit of 102.6°F (n=8). The other pilots in the crews had elevated core temperatures that were also close to reaching the permissible limit of 102.56°F. It is estimated, based on rate of core temperature increases, that they could not have continued for more than 10-15 additional minutes before reaching their core temperature limit.

Core temperature increased, but at a significantly slower rate, in the hot condition while wearing the lighter weight and more permeable MOPP0 ABDU flight uniform (0.33°F/hr). In the cool (70°F) condition, while the test subjects walked on the treadmill, the encumbered MOPP4 uniform caused an initial moderate, but tolerable, increase in core temperature. After transfer to the simulator, where metabolic rates declined to near baseline, the core temperature gradually returned to normal (appendix A).

Average maximum core temperatures in the simulator were 99.68°F for the MOPP0-cool condition, 99.56°F for the encumbered MOPP4-cool condition, 99.84°F for the MOPP0-hot condition, and 102.01°F for the encumbered MOPP4-hot condition.

During the simulated preflight, the average calculated (Epstein et al. 1987) metabolic rate while wearing the ABDU uniform was 357 watts and 426 watts for the encumbered MOPP4 ensemble (appendix A). At least partly because of the higher metabolic rate associated with wearing the encumbered MOPP4 ensemble, core temperatures were significantly higher for that ensemble when averaged across the two environmental temperature conditions (statistically significant main effect for type of flight uniform). Average and maximum core temperatures during simulator sessions showed

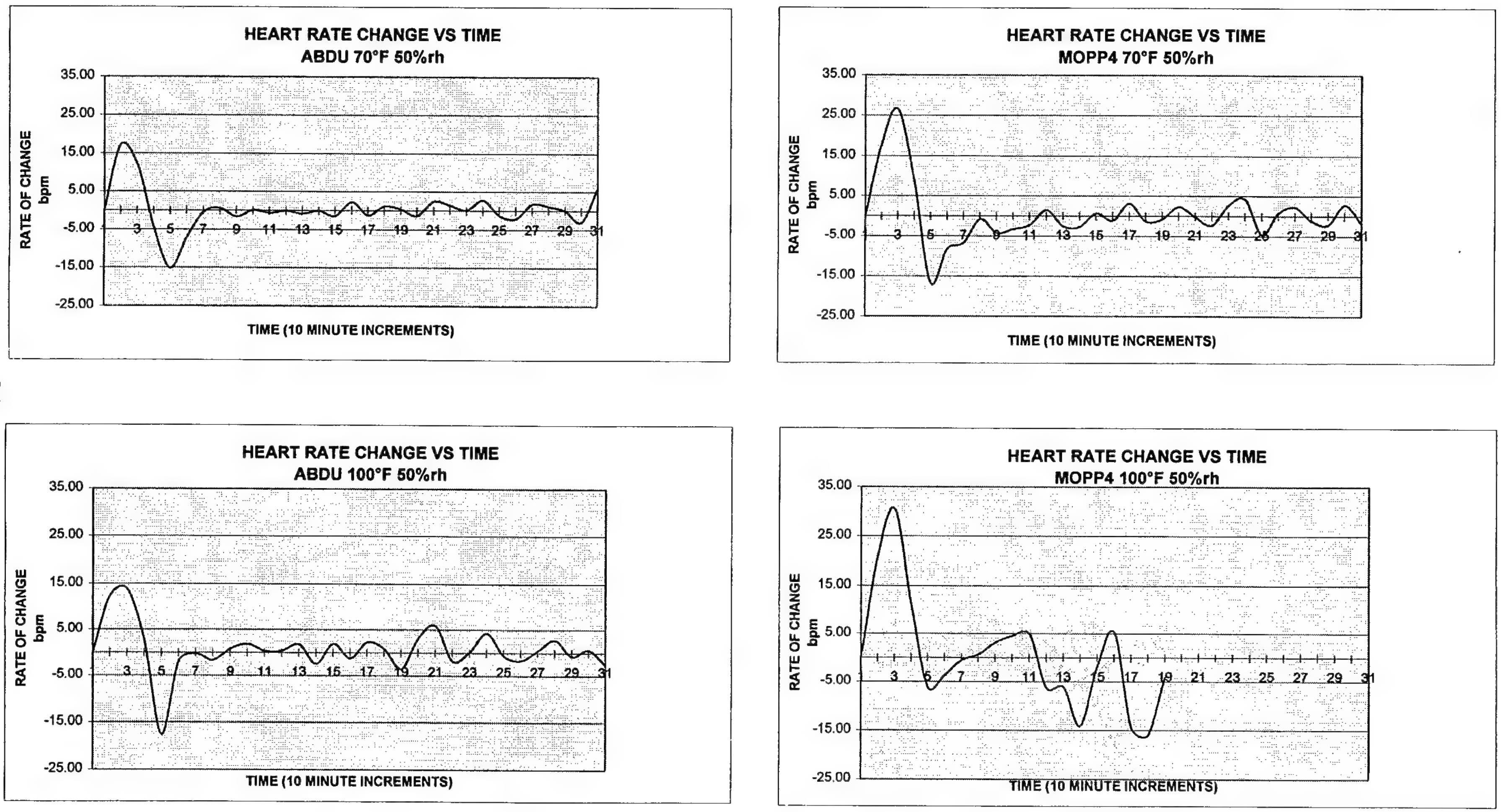


Figure 11. Rate of change graphs for heart rate.

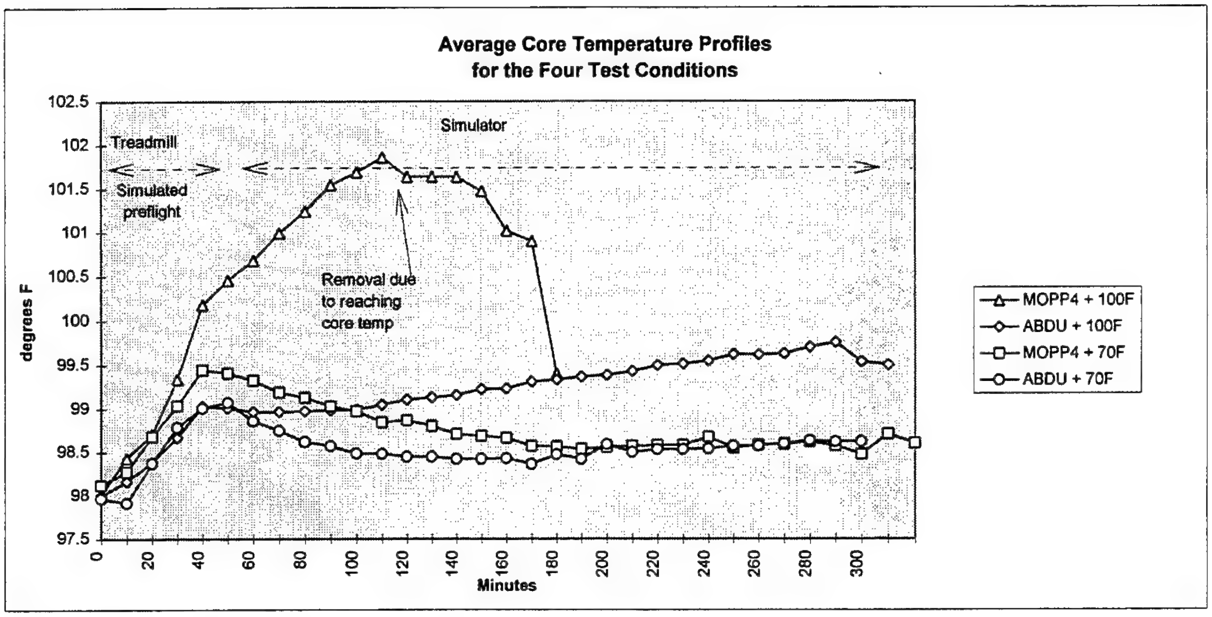


Figure 12. Average core temperature profiles.

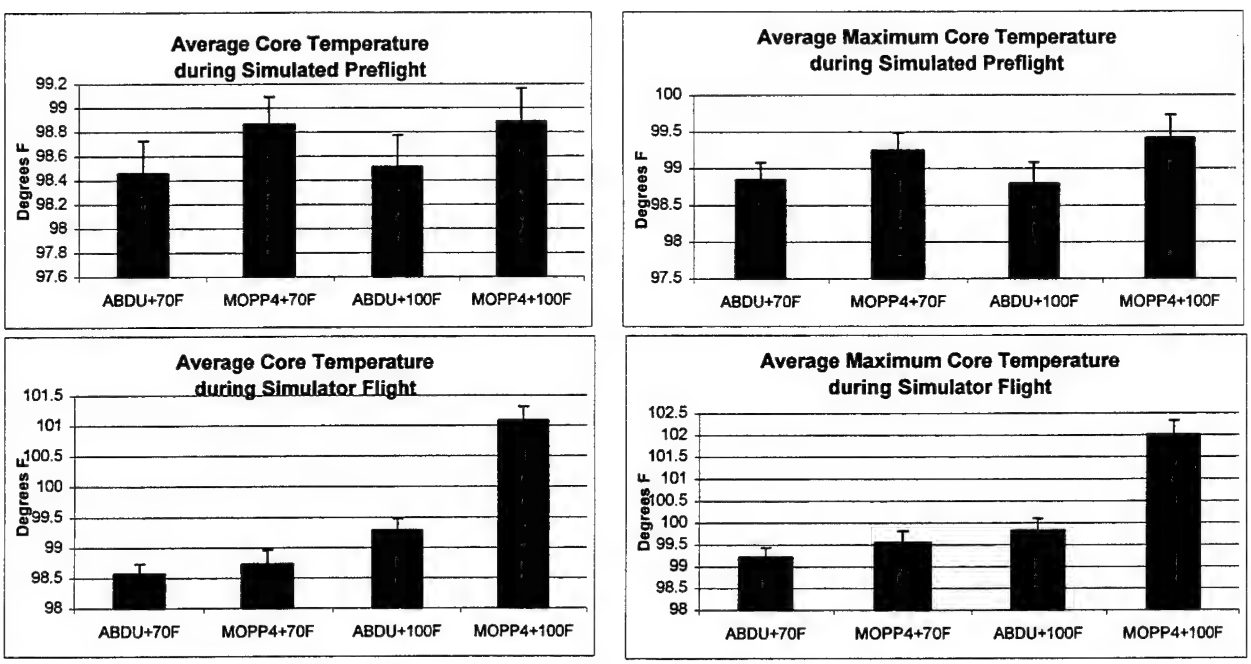


Figure 13. Average and maximum core temperature charts.

statistically significant effects for both environmental temperature and type of uniform, along with an interaction effect (appendix B).

Graphical depiction of average rates of core temperature change versus time are provided in figure 14. The initial rapid rates of core temperature increase occurred during the first 10 minutes on the treadmill (simulated preflight inspection). After the 20-minute treadmill session was completed, the rate of core temperature increase diminished but remained positive for a 10-15 minute lag period for all conditions except the MOPP4-hot condition. Core temperature increases persisted in the latter condition throughout the test session. The oscillations in the core temperature change rates exhibit a periodicity of approximately 20-30 minutes which corresponds to the time period between standard set of maneuvers and MATB performance testing versus flying NOE and contour.

While taking the 10-minute MATB computer performance test, the left-seat pilot typically moved his/her seat back all the way. This moved that pilot out from directly under the bank of overhead heat lamps (see figure 15). It is possible that this partially accounted for the core, and in similar manner, skin temperature (see below) oscillations. Core temperature change rates for the worst case test session, MOPP4-hot, became largely negative after the tenth 10-minute time interval due to an averaging effect between those volunteers who were removed from the test conditions due to reaching core temperature limits and were recovering, versus those who were more heat tolerant and able to continue longer in the heated simulator.

Mean total body heat storage in watts was calculated from the average core temperature profiles for each of the test conditions, mean test subject weight (78.8 kg), and a specific heat for average body tissue of 3.49 kJ/kg*C. The heat storage profiles for the cool (70°F) conditions were very similar (figure 16). For the MOPP0 and MOPP4 uniforms, there were 319 and 347 watts, respectively, of heat storage during the 20-minute walk on the treadmill. After completing the treadmill session, heat storage declined back to zero (baseline). In the hot conditions, however, heat storage increased throughout the test sessions. The rate of increase in heat storage in the hot condition was much higher for the encumbered MOPP4 uniform. Estimated maximum heat storage in the hot condition for the MOPP0 and MOPP4 aviator ensembles were 627 and 1445 watts, respectively. However, note that since core temperatures were primarily increasing during those test conditions, and because the calculation used a rectangular integration formula, these last two heat storage results are probably slightly overestimated (also see section on Fluid balance and dehydration on page 38).

Core temperature was also measured in eight test subjects with an ingestible temperature sensing and transmitting pill. As indicated in table 4, the core temperature pill data were often inaccurate in comparison to the rectal probe. Figure 17 also provides statistics regarding the relatively numerous instances of obviously spurious temperatures or transient signal losses. Overall, 24 percent of the downloaded data from the CorTemp * pill data logger consisted of error messages. Temperatures from

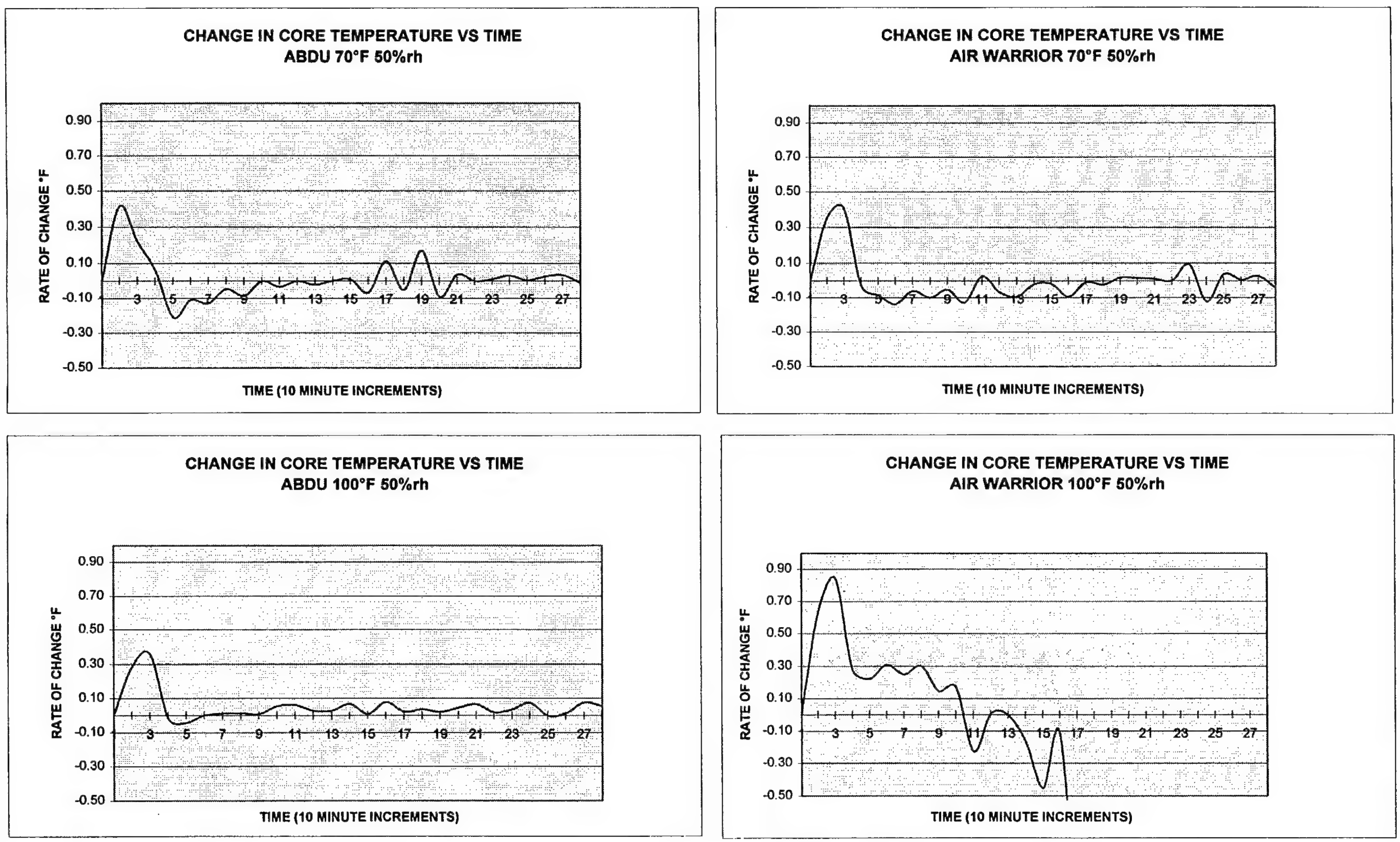


Figure 14. Rate of change graphs for core temperature.

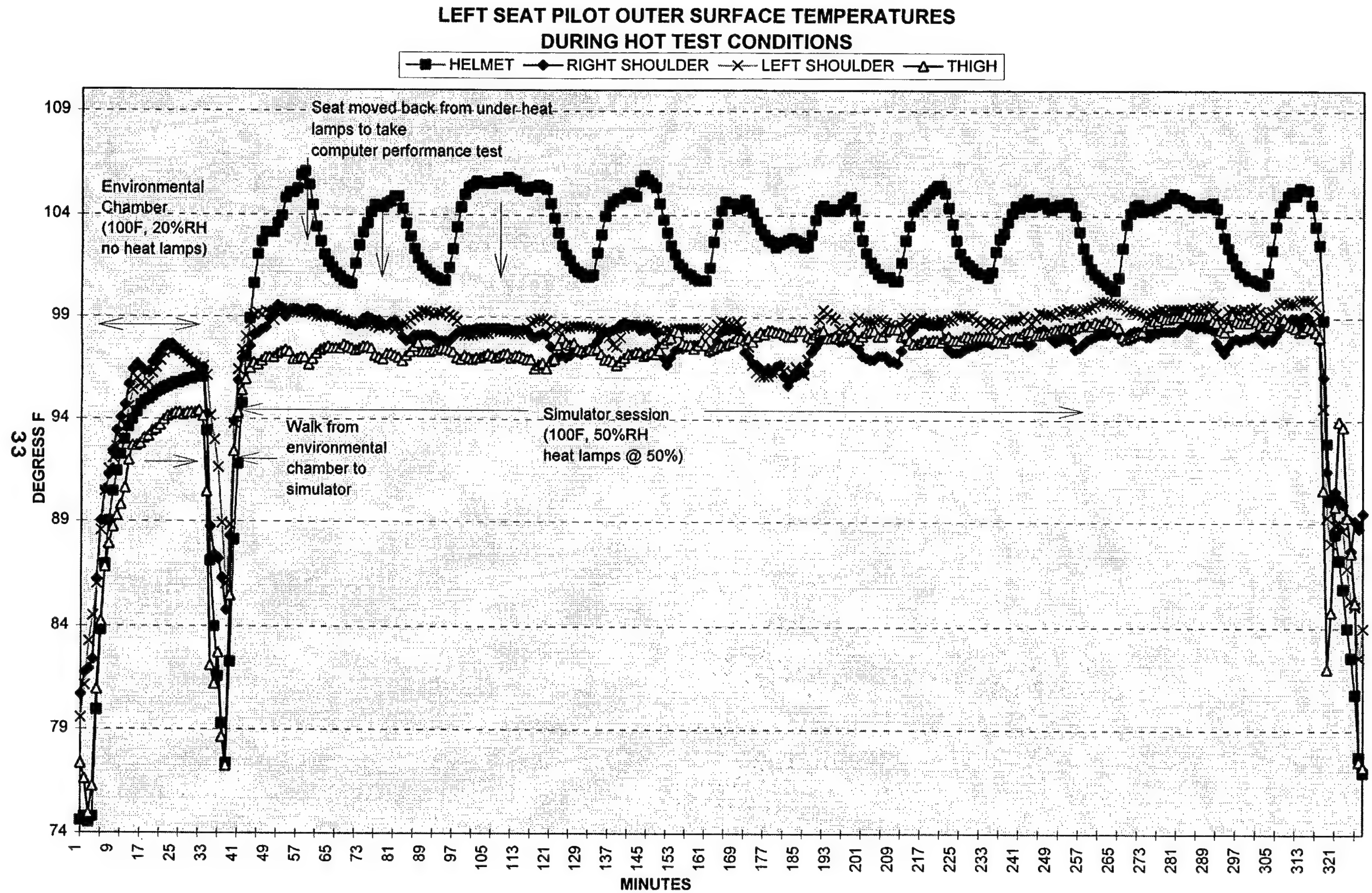


Figure 15. Outer surface temperatures.

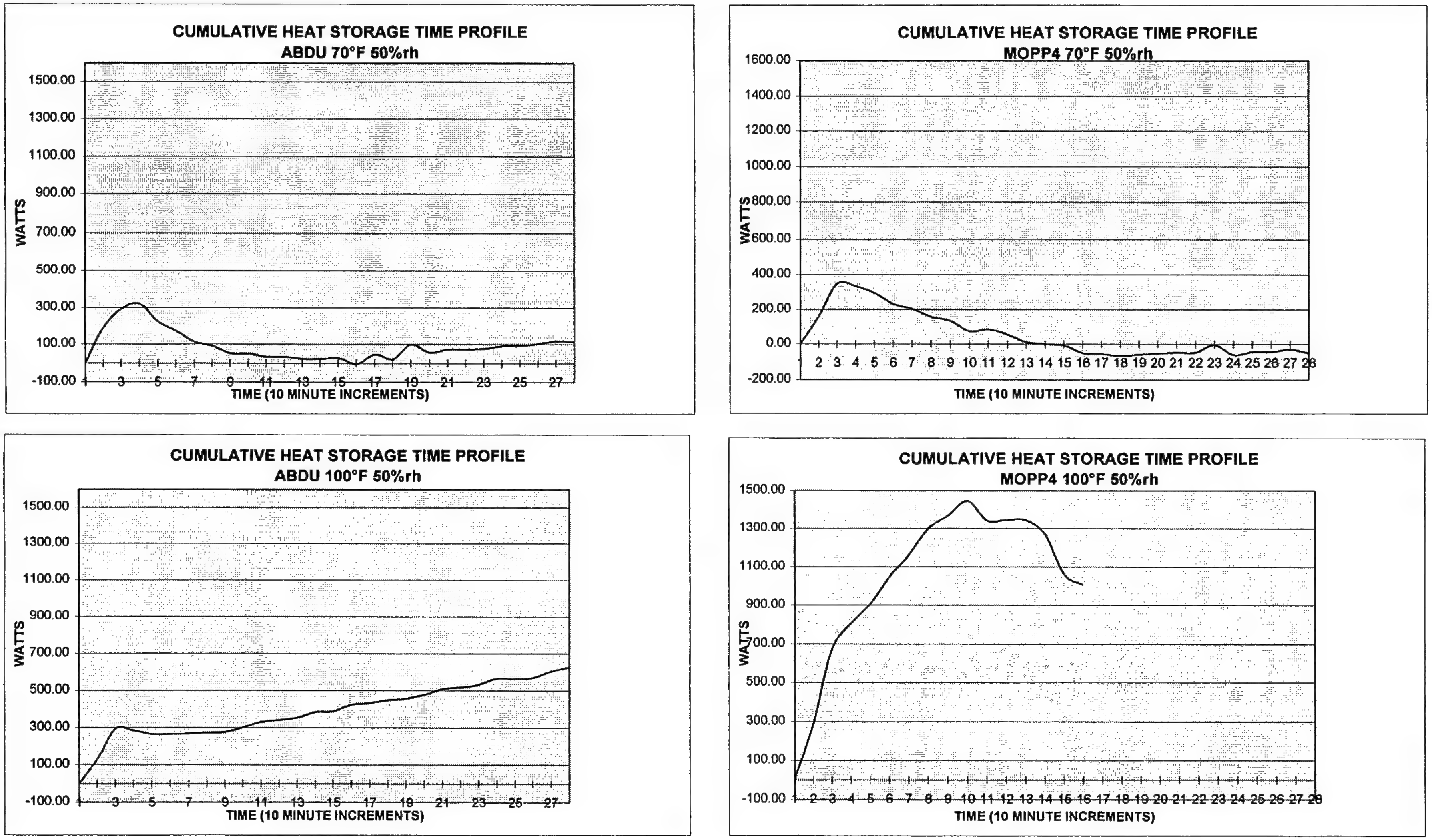


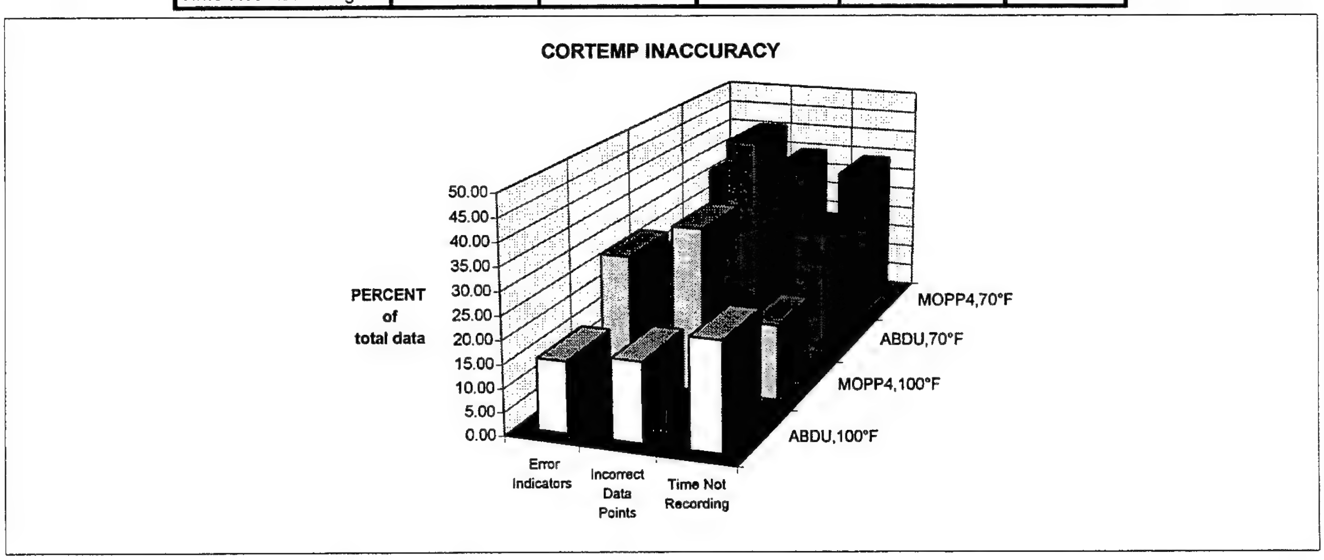
Figure 16. Cumulative heat storage time profiles.

Table 4.

CorTemp inaccuracy table and graph.

	TS1	TS3	TS5	TS7	TS12	TS15	TS17	AVG
ABDU, 70°F								
% Error	39	3	22		35		4	20.6
% incorrect	57	5	30		46		100	47.60
%not recorded	41	0	38		56		0	27.00
MOPP4,70°F								
% Error	60	1		23	31	36	43	32.33
% incorrect	100	6		13	31	10	48	34.67
%not recorded	73	0		0	35	50	46	34.00
ABDU, 100°F								
% Error		10	1	15		35	15	15.20
% incorrect		24	4	27		23	7	17.00
%not recorded		41	0	0		37	38	23.20
MOPP4, 100°F								
% Error		59	0	46	13		22	28.00
% incorrect		69	22	33	5		49	35.60
%not recorded		26	0	0	0		55	16.20

Percent of data	ABDU,70°F	MOPP4,70°F	ABDU,100°F	MOPP4,100°F	AVG
Error Indicators	20.6	32.33	15.20	28.00	24.03
Incorrect Data Points	47.60	34.67	17.00	35.60	33.72
Time Not Recording	27.00	34.00	23.20	16.20	25.10



the CorTemp * telemetry pill recorded properly 76 percent of the time, however, of those data, only 65 percent were considered to be correct (table 4). These findings indicated that, although more convenient and comfortable for the test subject, the core temperature pill is probably not an adequate method for monitoring core temperature when considering test subject safety and data accuracy. This was consistent with similar conclusions reported by Stephenson et al. (1992).

<u>Skin temperature</u>

Mean and range of core and skin temperatures at four locations are enumerated in the table below. Chest temperatures rose the most during the test sessions. Compared to the least thermally stressful condition (ABDU MOPP0, 70°F), mean chest temperature was 1.52°F greater in the encumbered MOPP4, 70°F condition, 1.85°F greater in the ABDU MOPP0, 100°F condition, and 4.68°F in the encumbered MOPP4, 100°F condition. The overall correlation between chest and core temperatures was 0.82. The correlations for the other skin temperatures with core temperature were smaller in magnitude.

Table 5.

Core and skin temperature means and ranges by condition.

	ABDU MOPP0+70F			encumbered MOPP4+70F		
	Avg	Max	Min	Avg	Max	Min
Core	98.17	98.38	97.90	98.66	99.99	97.52
Arm	92.04	92.89	91.22	95.25	99.97	89.42
Chest	96.07	98.04	93.70	97.59	100.13	94.30
Thigh	89.11	90.66	88.30	91.97	98.40	86.13
Leg	90.43	91.62	89.04	90.27	95.23	85.75
	ABDU MOPP0+100F			encumbered MOPP4+100F		
	Avg	Max	Min	Avg	Max	Min
Core	99.15	100.78	97.90	101.07	102.31	99.79
Arm	97.16	99.91	93.51	100.59	101.84	99.03
Chest	97.92	100.49	93.49	100.75	103.75	98.96
Thigh	96.36	99.57	91.62	100.51	102.00	98.38
Leg	95.47	99.82	89.13	99.08	100.71	97.56

The graphs in figure 18 provide a visual comparison of core and skin temperature profiles for the four different test conditions. All the skin temperature profiles (chest, arm, thigh, and lower leg) in the most thermally stressful condition (MOPP4, 100°F) were shifted upward by 6-10°F compared to the baseline ABDU, 70°F condition. Additionally, wearing the encumbered MOPP4 ensemble was associated with a much reduced core-chest temperature gradient compared to that which occurred when wearing the MOPP0 ABDU flight uniform. Elevated skin temperature can be a

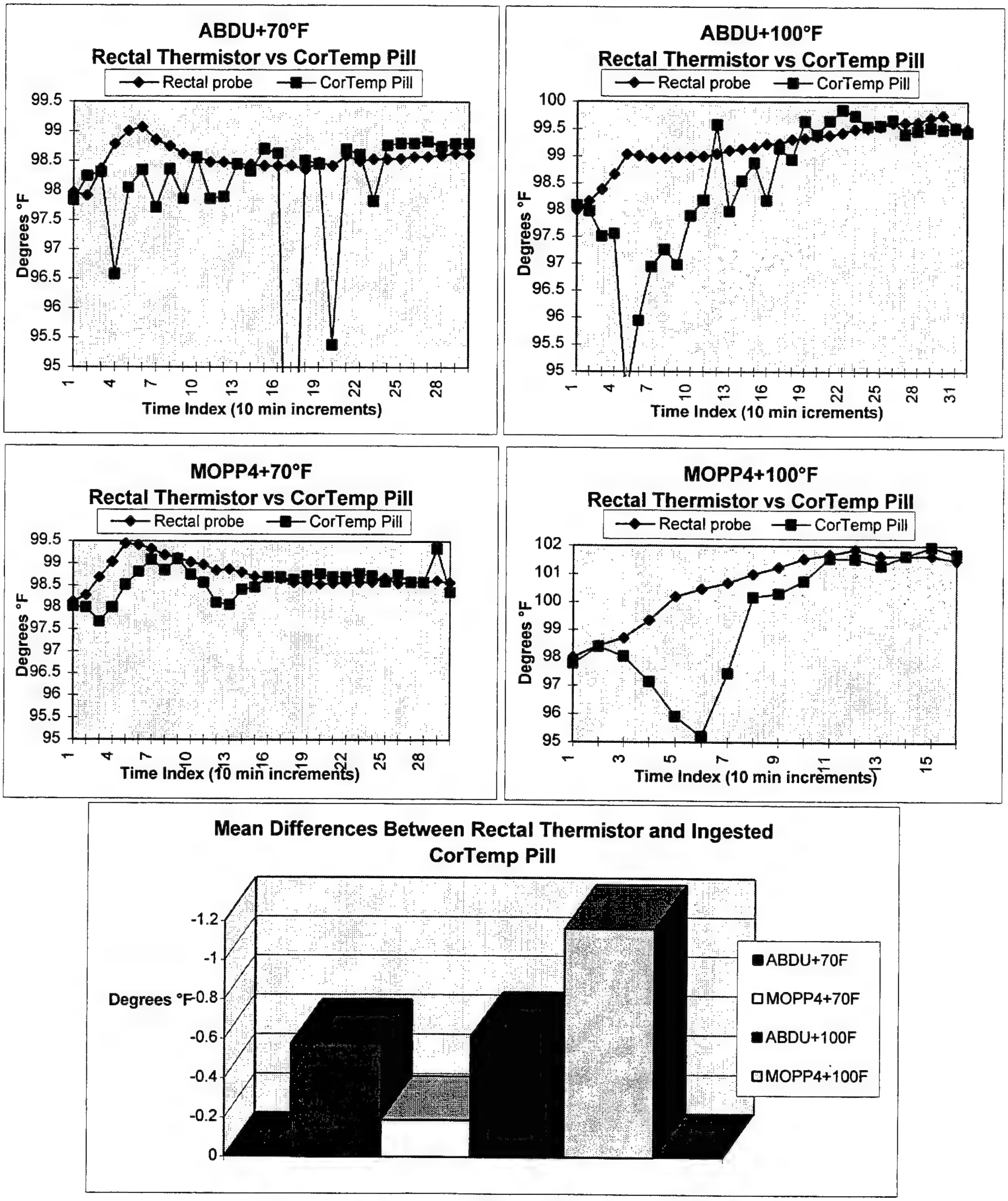


Figure 17. Rectal thermistor vs CorTemp pill.

significant contributor to thermal stress discomfort. It also implies that the various components of the flight ensembles overlying the sensors had high heat transfer resistance values. These results also suggest that the thick, heavy ballistic protective ceramic armor plate essentially blocks heat dissipation from the anterior chest.

As one might have expected, skin temperatures for the volunteer aviators consistently revealed a proximal to distal gradient. Core and chest skin temperatures were greater than the lower skin temperatures occurring distally over the extremities.

Figure 19 shows that the weighted mean skin temperature time profiles were shifted upward from the baseline (MOPP0 70°F) condition for the three other conditions. Mean skin temperature was most elevated for the encumbered MOPP4, 100°F condition, followed by the ABDU, 100°F and encumbered MOPP4, 70°F conditions. This was the same order as for average heat stress ratings calculated from the mood and symptoms questionnaire.

The average rates of change of mean weighted skin temperature versus time while the volunteer aviators were in the simulator are depicted in figure 19. The rates must be interpreted in light of the skin versus time graphs. For example, the relatively large rate of skin temperature decrease after completing the simulated preflight treadmill session for the MOPP4-cool condition compared to the ABDU-cool and hot conditions was due to the more rapid drop in skin temperature from higher levels attained while walking on the treadmill with the occlusive encumbered MOPP4 uniform.

Fluid balance and dehydration

The sweat and fluid balance charts (figures 20 and 21) indicate that the rate (1430 cc/hr) and cumulative amount of sweat loss (2495 cc) were substantially greater for the encumbered MOPP4-100°F condition compared to the MOPP4-70°F condition (183 cc/hr and 950 cc). The encumbered MOPP4 uniform was also associated with significantly greater sweat retention and proportionately less evaporated sweat (73 percent retained and 27 percent evaporated in the hot condition vs. 43 percent retained and 57 percent evaporated in the cool condition) than the MOPP0 ABDU uniform (34 percent retained and 66 percent evaporated in the hot condition vs. 0 percent retained and 100 percent evaporated in the cool condition).

The sweat retained in the ensemble represented total lost cooling potential of 0 watts in MOPP0-70°F, 255 watts in MOPP0-100°F, 430 watts in encumbered MOPP4-70°F, and 1117 watts in MOPP4-100°F (calculated on the basis of 580 Cal per liter of retained sweat). This was equivalent to a calculated potential reduction in peak core temperature of 0°F for the MOPP0-70°F condition, 1.00°F for the MOPP0-100°F condition, 1.69°F for the MOPP0-70°F condition, and 4.39°F for the MOPP0-100°F condition. In the hot conditions, the unutilized cooling effect of the retained sweat would have been just sufficient to maintain euthermia.

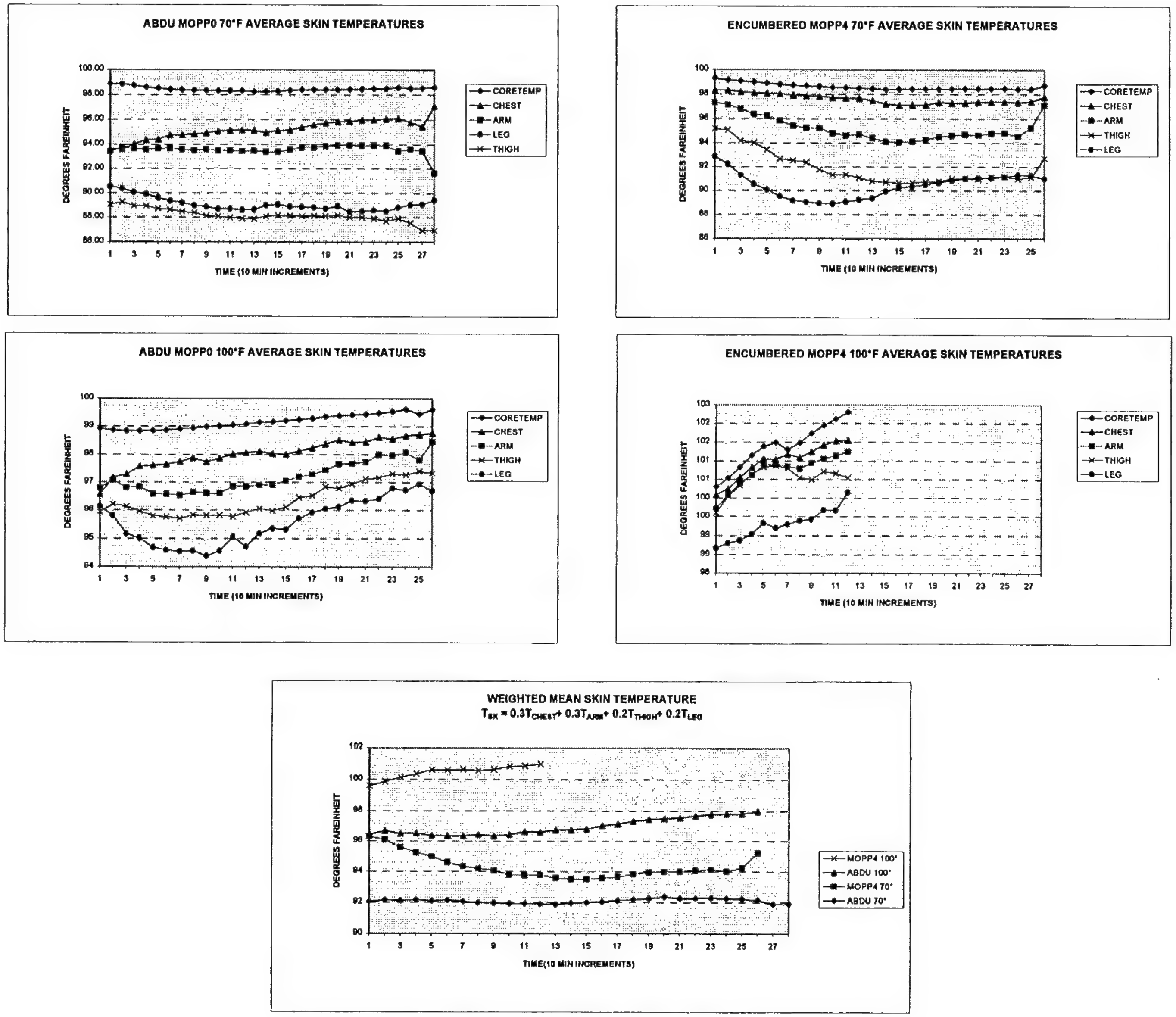


Figure 18. Skin temperature graphs.

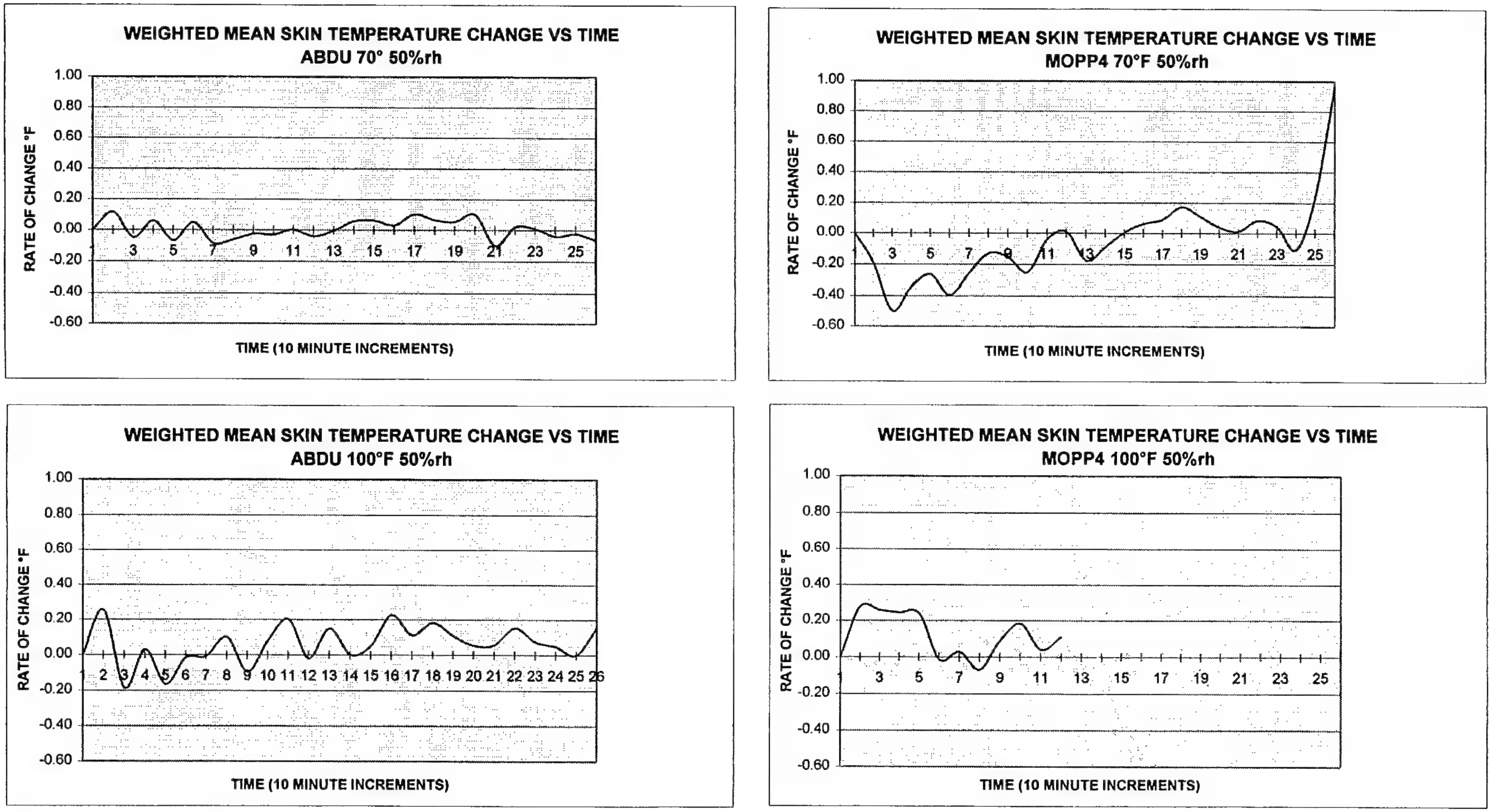
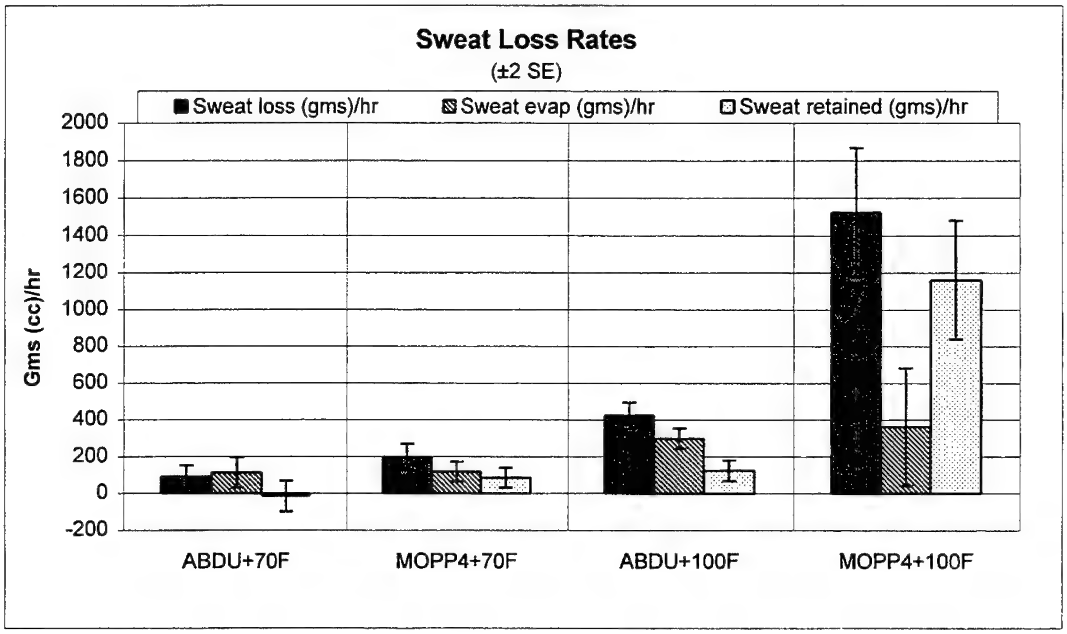


Figure 19. Rate of change graphs for skin temperature.



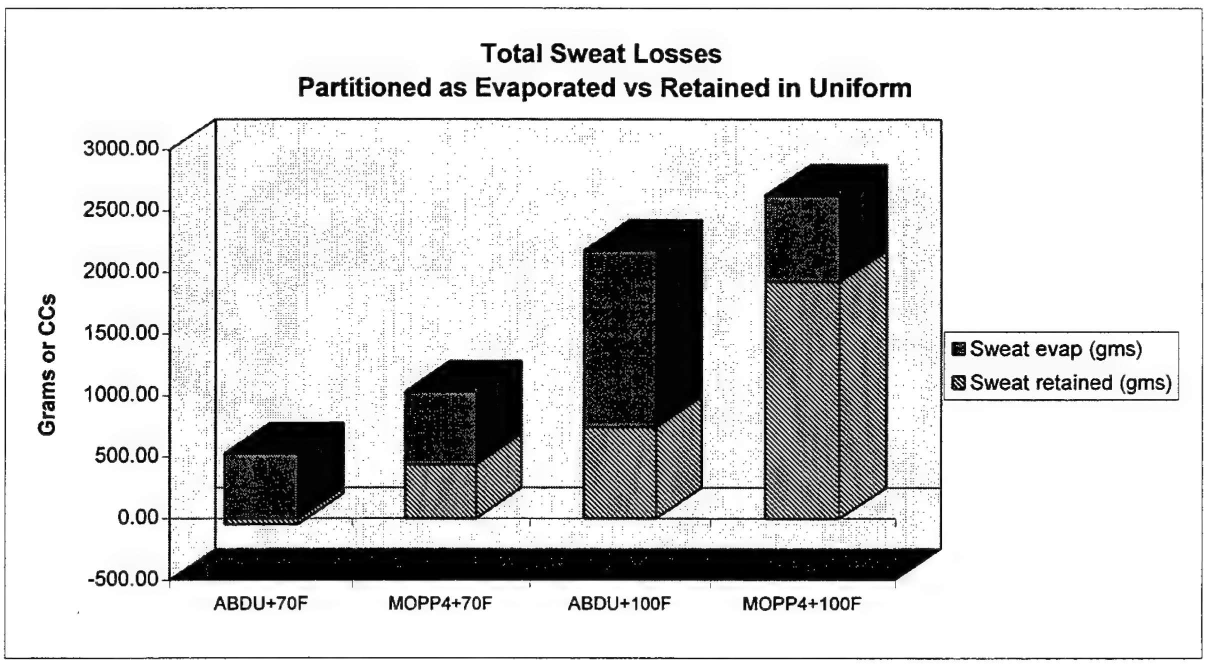
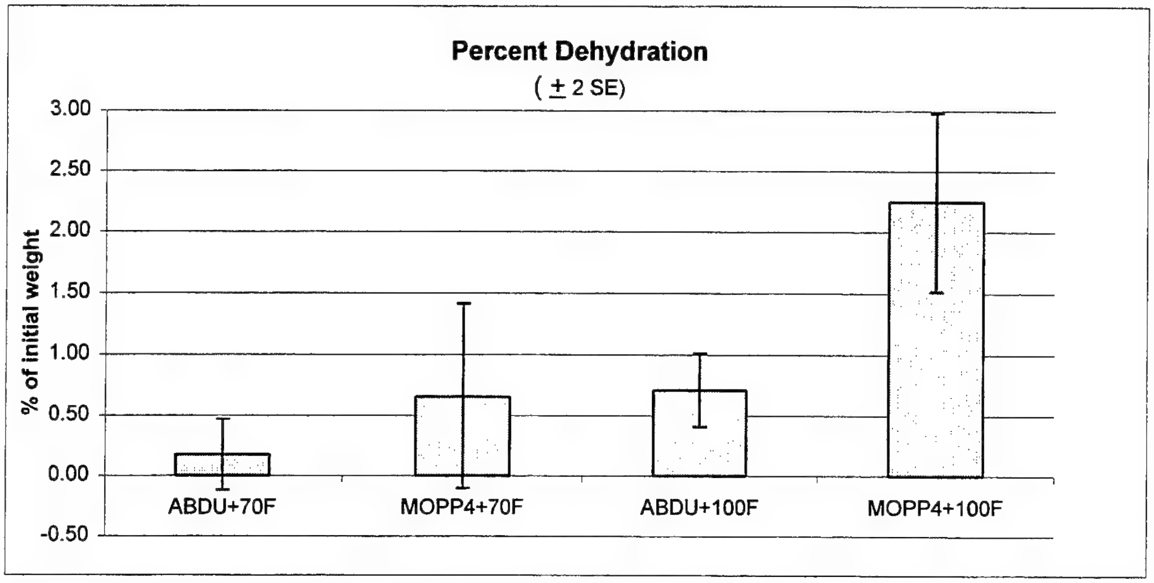


Figure 20. Sweat loss profiles.



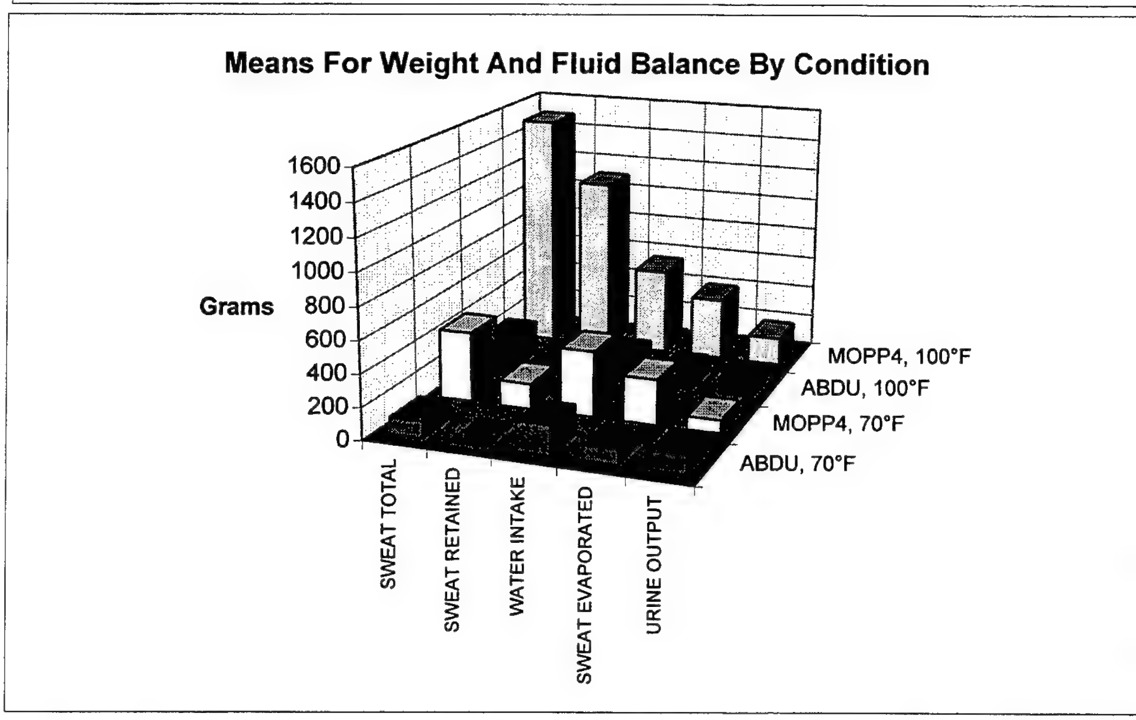


Figure 21. Means for sweat and fluid balance.

Although physiological endurance in the encumbered MOPP4-hot condition approximately one third that for the other three conditions, that condition was associated with 2.25 percent dehydration vs 0.71 percent in MOPP4-cool, 0.6 percent during MOPP0-hot, and 0.18 percent during MOPP0-cool (appendix B).

Psychological results

The psychological, or subjective, effects of the test conditions were measured by the use of three questionnaires. A composite hot spot and mood and symptoms questionnaire was formulated specifically for this study, whereas the POMS and TLX questionnaires were developed elsewhere. The data from the questionnaires provided a quantitative estimate of psychological stress the volunteer incurred while exposed to the different conditions of flight ensemble and environmental conditions.

Uniform associated pressure-point (hot spot) discomfort

The volunteer aviators answered a verbally administered questionnaire every 30 minutes that provided locations and severity ratings for hot spot discomfort. Figure 22 graphically depicts the variation in distributions of hot spots ratings across the four test conditions. The distribution of hot spots varied according to type of flight uniform and duration of the test sessions. While wearing the encumbered MOPP4 ensemble, hot spots were primarily located about the head and back (92 percent and 72 percent of total hot spot complaints in the hot and cool condition, respectively). When wearing the more comfortable, lighter weight ABDU MOPP0 uniform, total hot spot discomfort was less and the distribution was primarily over the back and buttocks (68 percent and 61 percent of total hot spot complaints in the hot and cool conditions, respectively).

Time weighted hot spot intensity ratings were highest for the encumbered MOPP4-hot condition (figure 23a). High average hot spot intensity for the encumbered MOPP4 condition were primarily due to high scores for hot spots about the head due to the CB mask-helmet combination. (Helmet fit with and without the CB mask was performed on all the volunteer aviators prior to testing.) The sum, or equivalently, the integral of the hot spot intensity scores provides an indicator of cumulative discomfort, or stress, from hot spots over the entire mission (figure 23b). These data indicate that total hot spot discomfort, or stress, was equivalent for both cool and hot encumbered MOPP4 conditions. That is, although mean hot spot intensities were greater in the encumbered MOPP4-hot condition, those sessions were of shorter duration; therefore, the total hot spot related stress was similar to that incurred during longer exposure to less intense hot spot discomfort while in the cool condition.

Mood and symptoms

The mood and symptom questionnaire was administered before and approximately every 30 minutes after the volunteer pilots began the treadmill session in the environmental chamber. The average responses with respect to elapsed time across

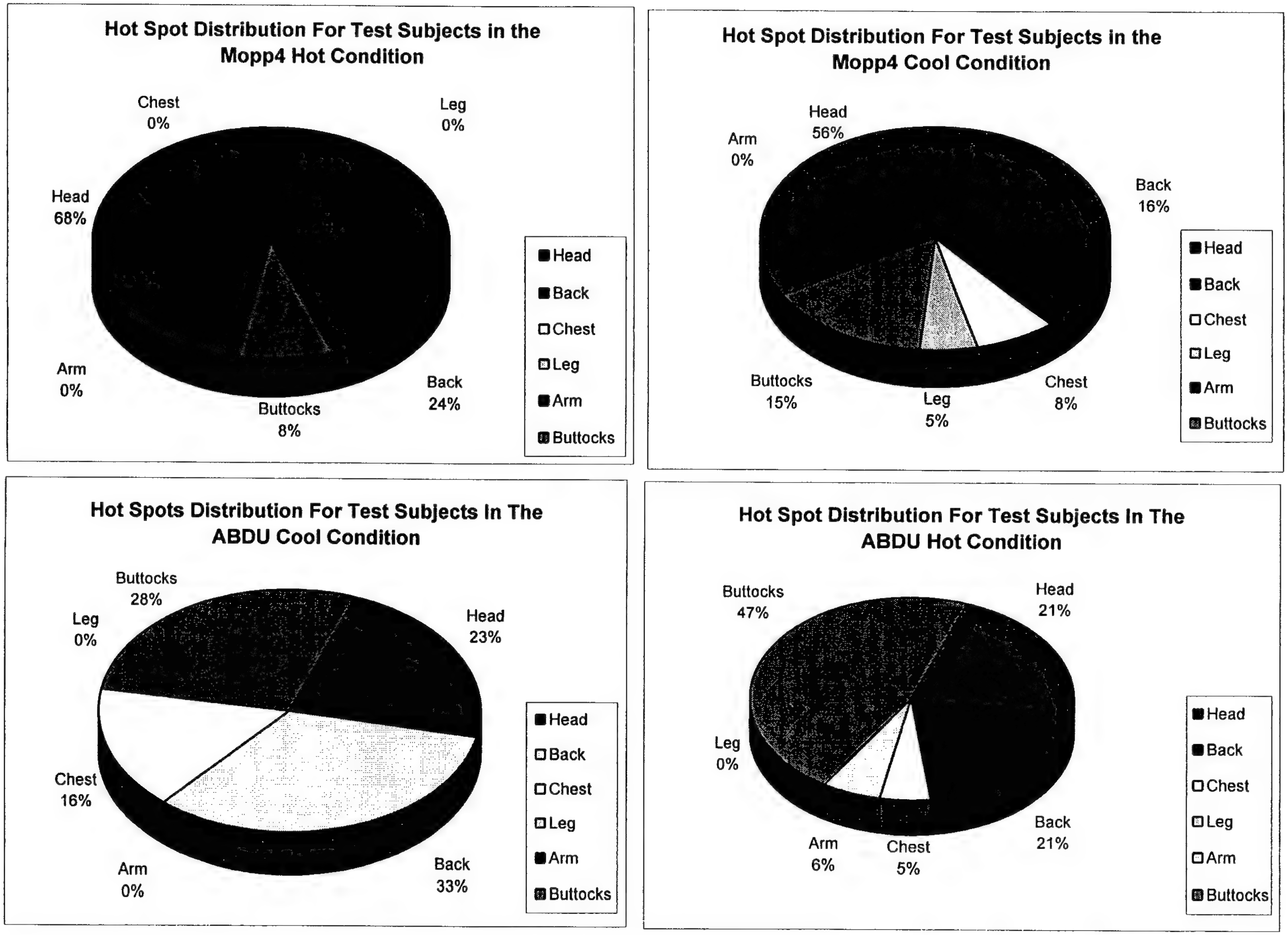
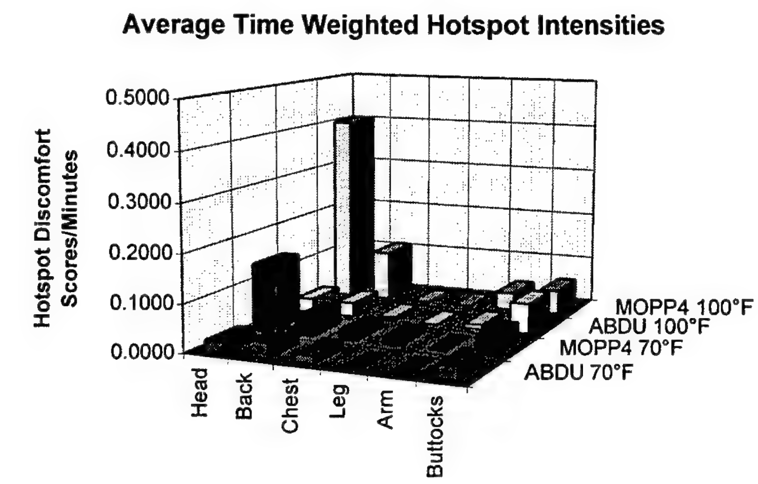


Figure 22. Hot spot distribution charts.



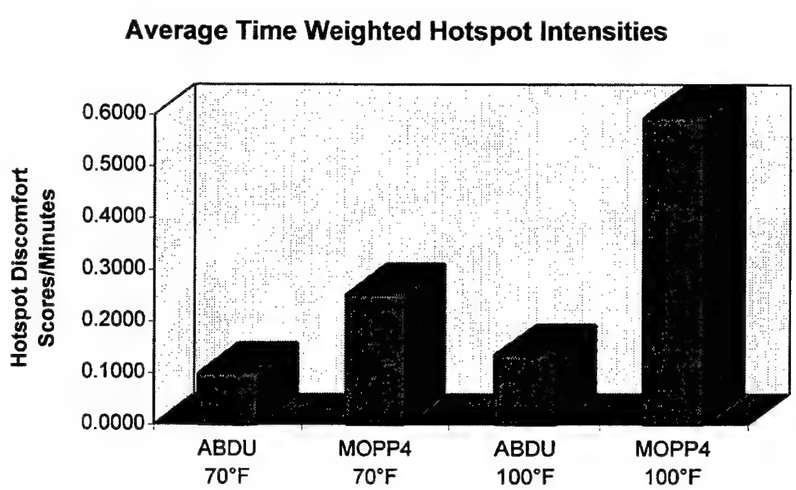
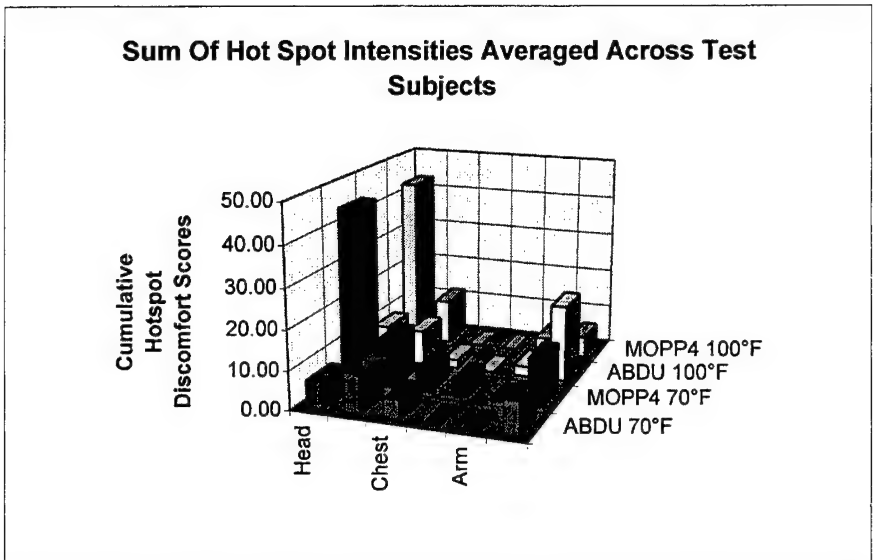


Figure 23a. Hot spot intensity charts.



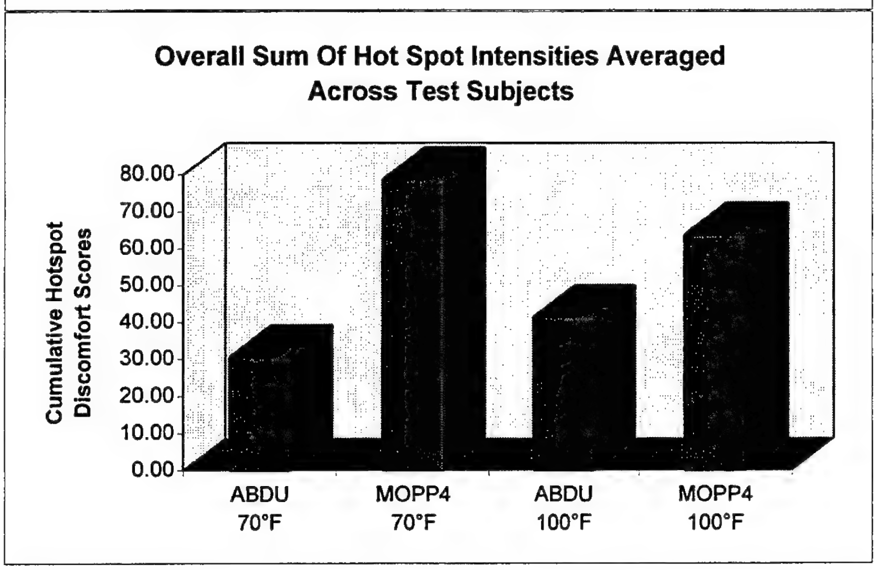


Figure 23b. Hot spot itensity charts (cont.).

the four test conditions are provided in figures 24a and 24b. Progressive increases in rating with respect to time (or equivalently, core temperature or heart rate, which also rapidly increased as functions of time in the MOPP4-hot condition) were most prominent during the MOPP4-hot condition. The repeated measures MANOVA and ANOVA results (figure 25 and appendix B) indicate that the encumbered MOPP4-hot condition was associated with significantly higher ratings for workload, composite stress, and heat stress, as well as for adverse symptoms such as nausea, dizziness, headache, and thirst. The encumbered MOPP4 ensemble also seemed to elicit a dysphoric mood response as reflected in higher ratings for depression and anger compared to the ABDU test conditions. Interestingly, in the encumbered MOPP4-hot condition, boredom ratings diminished over time in the simulator compared to the other conditions where it remained relatively constant. Conversely, ratings for other mood and symptoms increased quite prominently with respect to time in the MOPP4-hot condition.

POMS

The results from the mood and symptoms questionnaire were corroborated with the results of a standard POMS questionnaire that was completed by all test subjects immediately prior to and after each test session (appendix B and figure 24). The POMS results are depicted in figure 26 as average differences (pre-minus posttest session) across the four test conditions for the seven mood state scores. Positive values indicate lower values for a mood state after testing, whereas negative values correspond to larger POMS states values after testing. Pre minus post differences were used primarily to improve the readability of the graphical representation of the results. Vigor score changes were slightly less for hot and encumbered MOPP4 conditions. Changes in anger-hostility, fatigue-inertia, tension-anxiety, depression-dejection, and total mood disturbance scores were all larger for the encumbered MOPP4-hot condition.

TLX

The TLX questionnaire was administered every 30 minutes to the right seat pilot immediately after completion of each set of standard maneuvers, and to the left seat pilot immediately after completion of each 10-minute MATB. TLX questions were evaluated individually; composite TLX index values were not calculated. Mean ratings for the TLX questions across conditions are depicted in figure 24 and appendix B. These results indicated that flying the simulator and performing the MATB aviation-related psychomotor tasks were perceived as more physically and mentally demanding, required more effort, and caused greater frustration for the encumbered MOPP4-hot condition than during the other three conditions (figure 27).

Correlations and regressions

There were no correlations with a magnitude greater than 0.65 between characteristics of the volunteer aviators (age, height, weight), training (PT scores, heat illness prevention training), and flight hours (total, UH-60, and simulator) with composite

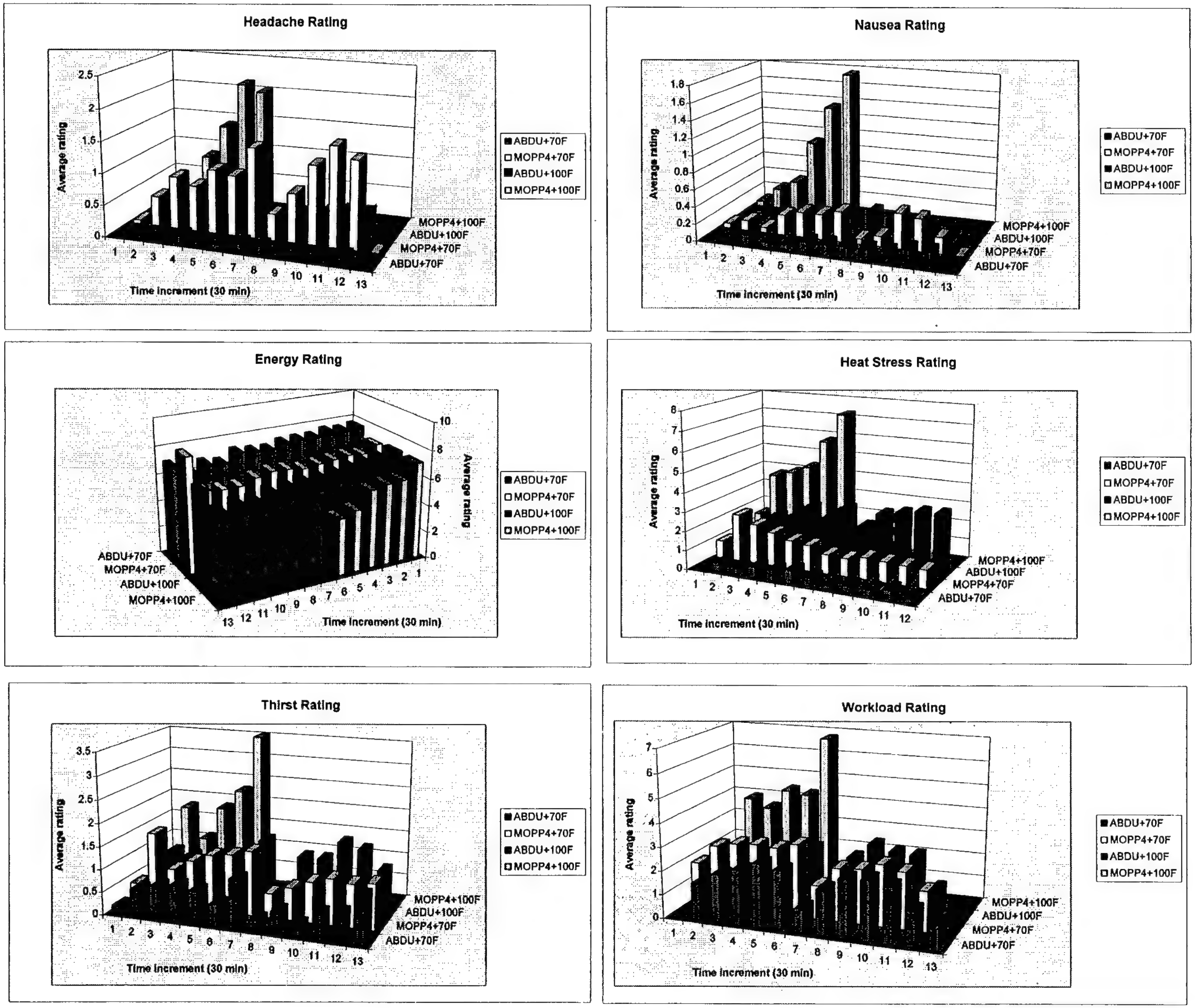


Figure 24a. Mood and symptom detail category charts.

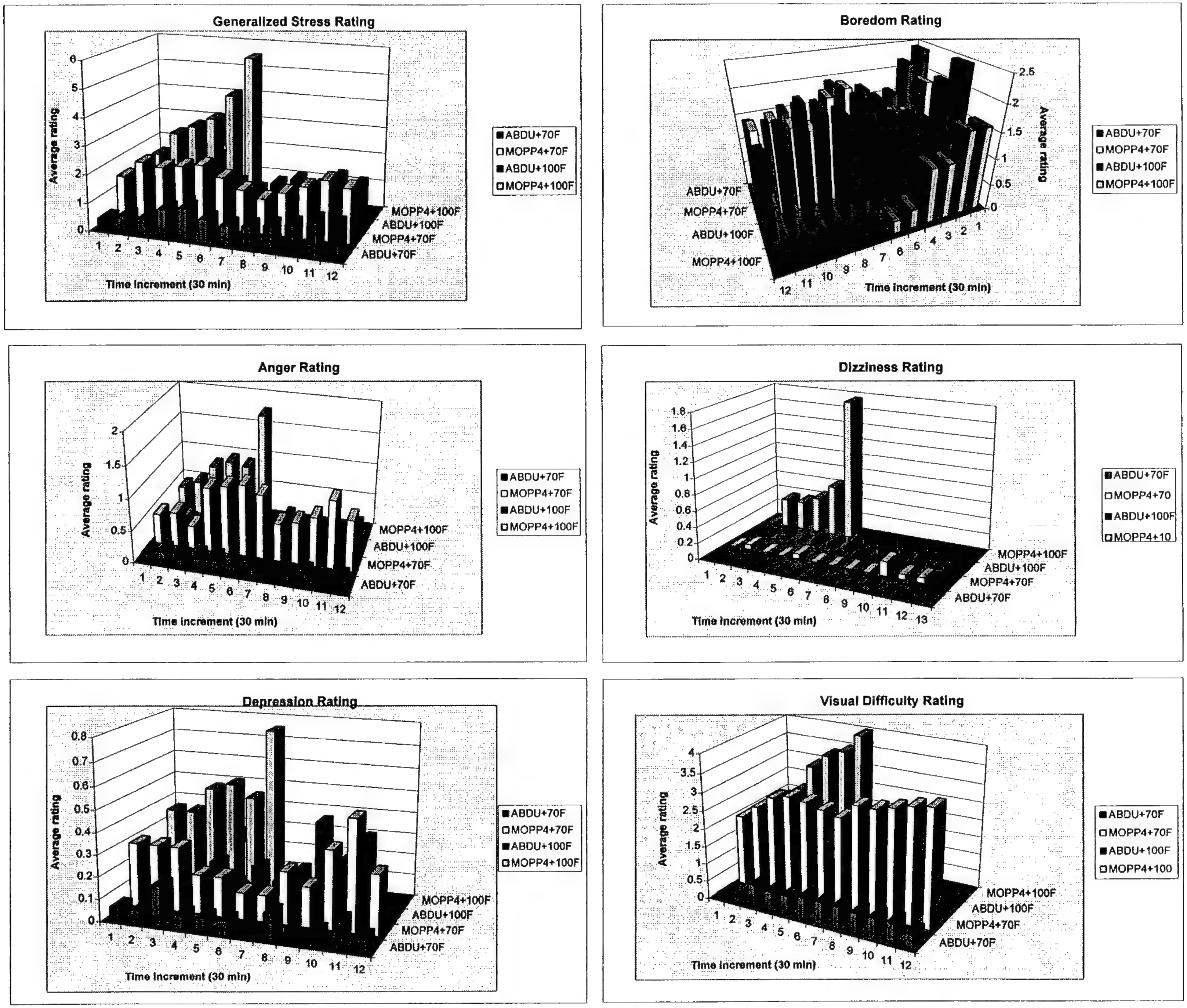


Figure 24b. Mood and symptom detail category charts (cont.).

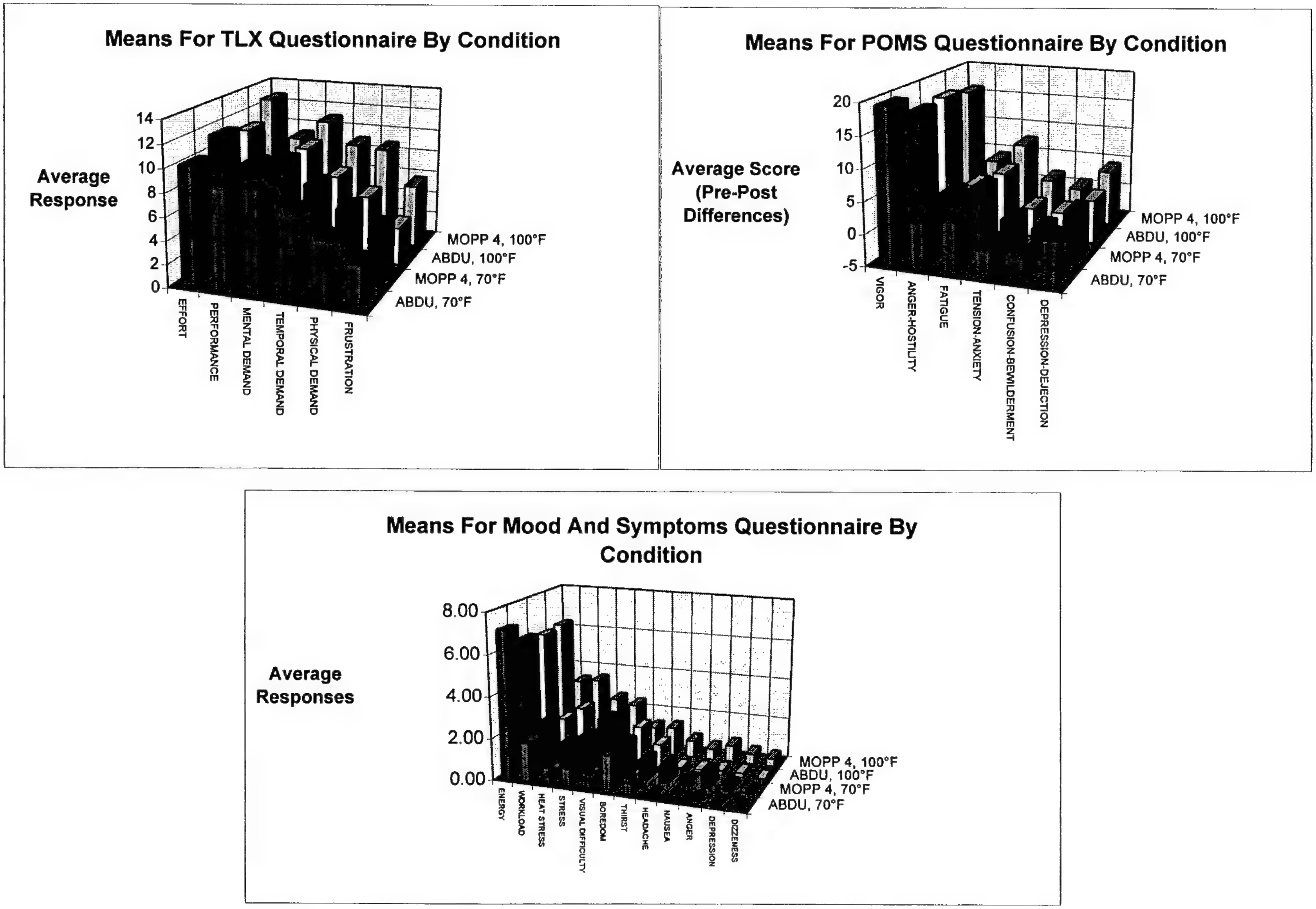


Figure 25. Means for questionnaires by condition.

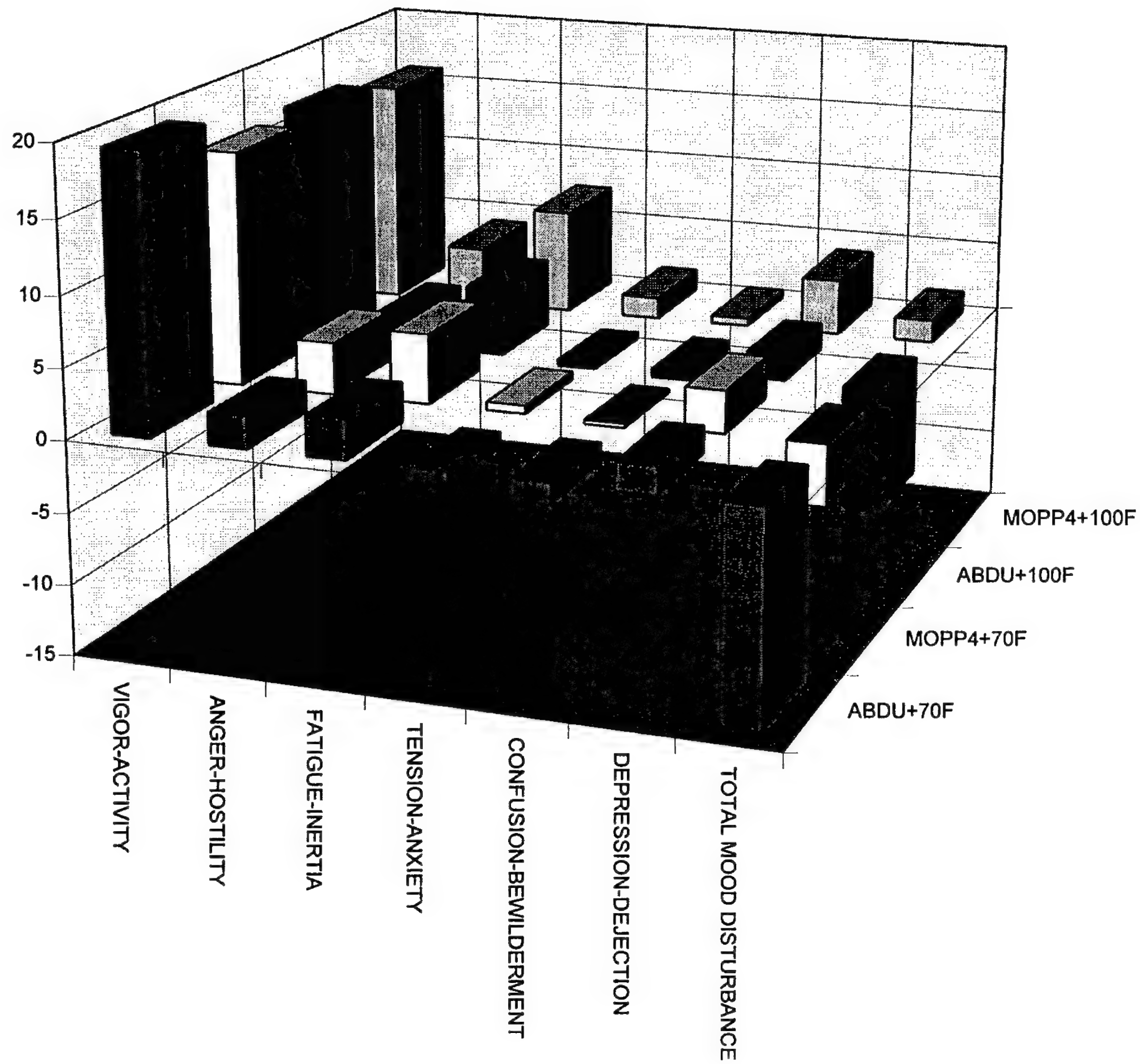


Figure 26. Profile of mood states: Pre- and posttest results.

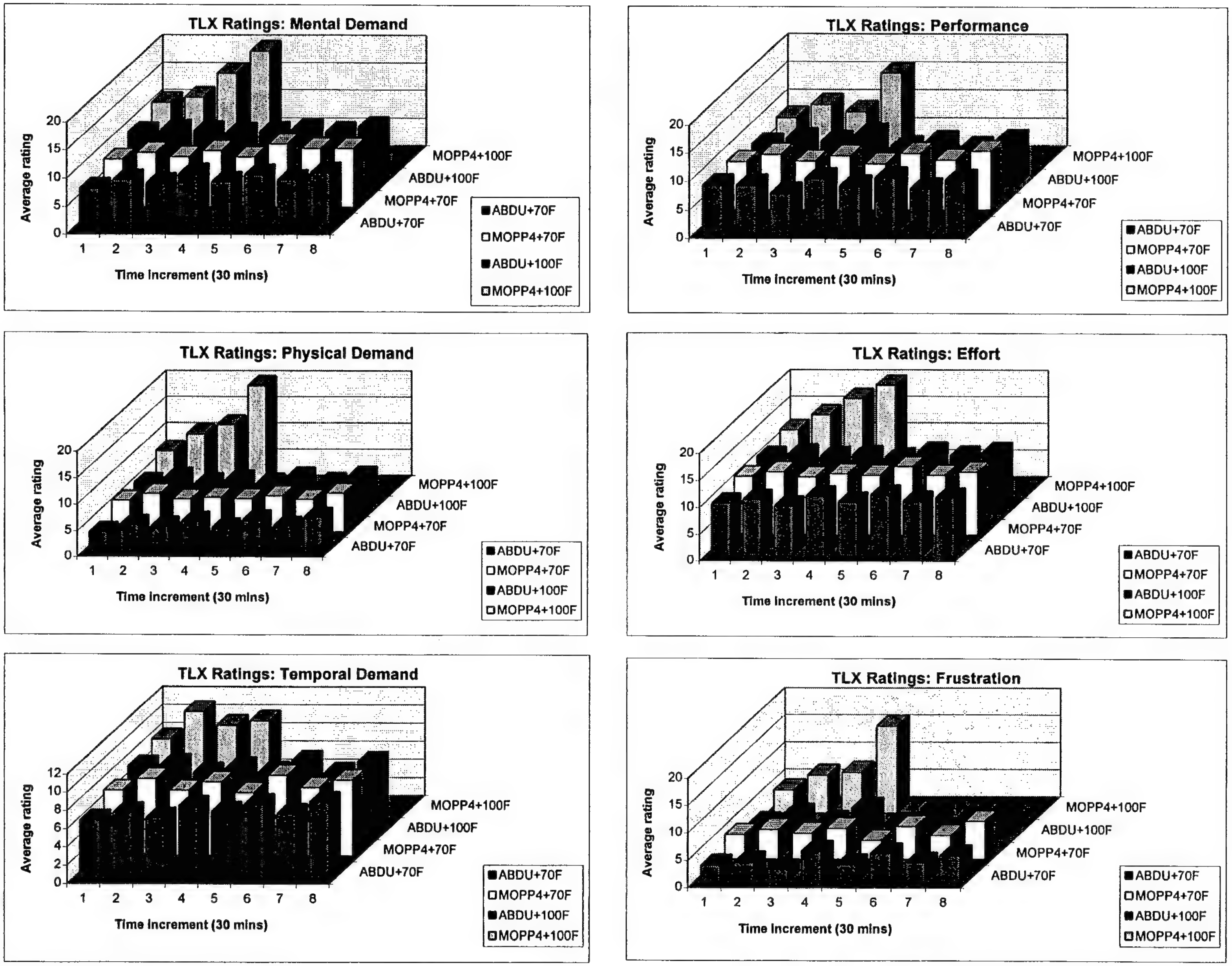


Figure 27. TLX response charts.

flight scores for the eight maneuvers or flight modes (HOV, HOVT, SL, LCT, LDT, RSRT, NOE, and Contour). Most of the significant ($p \leq 0.05$) correlations between these variables were less than |± 0.30| (appendix C). Such correlations are considered small and are not usually of practical importance. The largest significant correlation (| -0.6389|) between total UH-60 flight hours and composite score for the LCT maneuver was isolated, and presumably due to chance as a result of performing multiple exploratory post-hoc correlations.

Similarly, the magnitude of the significant correlations between aviator characteristics, training, and flight hours with physiological responses (maximum core temperature and heart rates, sweating rates, dehydration, and skin temperatures) were all less than 0.30, implying no meaningful correlations between those sets of variables (appendix C).

Maximum core and chest temperatures were and highly correlated (0.82). Maximum heart rate correlated maximally with maximum core temperature (0.66) and weighted mean skin temperature (0.67). As one would expect, percent dehydration was most highly correlated with sweating rate (0.69), while the latter was most correlated with maximum core temperature (0.75) and weighted mean skin temperature (0.73). The correlations between skin temperatures at the four different sites (chest, arm, thigh, and lower leg) were in the range 0.5-0.8. All these correlations were statistically significant.

Forward stepwise multiple regression analysis revealed that 57 percent of the variation in maximum heart rate for the volunteer aviators across all test sessions could be attributed to maximum weighted mean skin temperature, ambient temperature, and age, in that order. Height, weight, and PT score were less important, explaining an additional 8 percent of the variance. Forward multiple regression also showed that 80 percent of the variance in maximum core temperature could be predicted by weighted mean skin temperature (or chest temperature) and sweating rate.

Discussion

Aviators wearing the current encumbered MOPP4 aviator uniform in the hot condition incurred significantly more physiological and psychological strain as reflected in the dramatically elevated core temperature and heart rate profiles when compared to the ABDU MOPP0-cool condition. Responses for mood and symptoms, POMS, and TLX questionnaires indicated significantly increased discomfort, stress, and increased perceived workload for the MOPP4-hot condition. During the encumbered MOPP4-hot condition, physiological and psychological stress and strain became intolerable and caused endurance time to be reduced by approximately 67 percent, from 309 to 107 minutes. Endurance in the MOPP4-hot condition was, on average, only 33 percent of endurance times in the other, less severe conditions. Core temperatures rose rapidly when the study volunteers were in the encumbered MOPP4-hot condition.

The sweat and fluid balance data indicated that the rapid and sustained increase in core temperature in the encumbered MOPP4-hot condition was due largely to the resistance of the multiple layers of the uniform to the effective evaporation of sweat. Rates of sweating and sweat retained in the uniform while in the encumbered MOPP4-hot condition were both approximately 1 liter per hour greater than in any of the other three test sessions. The 1 liter per hour of retained sweat represented a loss of 580 watts per hour of potential evaporative cooling power.

The encumbered MOPP4 uniform caused increased ratings for discomfort and distraction from pressure points about the head due to the mask and helmet. While wearing the MOPP0 ABDU flight uniform, the majority of pressure points were from the back and buttocks due to the longer flight endurance with prolonged sitting.

Comparison of results with previous USAARL heat stress studies

Knox et al. (1982) conducted an in-flight evaluation of heat tolerance and CD aviator ensembles using USAARL's UH-1 research helicopter. The U.S. ensemble consisted of a two-piece Nomex flight suit, two-piece charcoal cloth laminated chemical defense overgarment, mask, hood, and rubber gloves, SPH-4 flight helmet, and combat boots. The insulation and permeability values of that ensemble were 2.57 (clo) and 0.29 (i_m) respectively. Mean cockpit WBGT during the test flights was 29°C (84.2°F). This was equivalent to a category III heat stress level, whereas the hot condition for the present study (90°F WBGT) represented the lower limit of the highest WBGT heat stress level, category V. Average in-flight tolerance times in the 1982 UH-1 study were 3.17 hours for the MOPP4 ensemble versus 3.89 hours for the MOPP0 Nomex flight uniform. Consistent with the higher ambient WBGT used in the present study, mean tolerance time for the volunteer aviators was only 1.78 hours for the MOPP4-100°F condition.

In the 1982 UH-1 study, mean heat stress tolerance time associated with wearing their MOPP4 ensemble was disproportionately depressed by a subgroup (cluster) of aviators who were heavier (90 vs 75.3 kg), older (33.5 vs 23.0 years), and less fit than the subgroup who were able to complete the missions. Among the heat intolerant aviators in the UH-1 study, core temperature and heart rate increased more rapidly compared to those in the tolerant subgroup. The latter established relatively stable tolerable plateaus for core temperature and heart rate. We did not experience this effect in our study, none of the correlations between pilots' age, height, weight, PT score, or previous flight experience and tolerance time in the MOPP4-100°F condition reached statistical significance.

Average sweat loss in the 1982 UH-1 heat stress study was 0.95 liters (98 percent evaporated) for those wearing the MOPP0 and 1.29 liters (only 36 percent evaporated) for those wearing the MOPP4 ensemble. Therefore, the greater water vapor impermeability and absorptivity of the MOPP4 ensemble prevented the use of 270 kcal worth of evaporative cooling from sweat that was not evaporated due to absorption retention in the ensemble.

The present study demonstrated that, during the 100°F condition, average sweat losses in the MOPP0 ABDU were 0.2 liters (54 percent evaporated) and in the encumbered MOPP4 over ABDU 1.48 liters (26 percent evaporated). Comparison across the two studies is difficult, because in the 1982 UH-1 study, humidity was not measured and ambient temperature was not a controlled factor. Obviously, lower values of average cockpit humidity in the UH-1 study versus our study could explain a considerable portion of the differences in percent of evaporated sweat.

Responses to the mood-state questionnaire administered during the 1982 UH-1 in-flight heat stress study did not reveal significant correlations with heat stress levels. The authors also noted a "dissociation between level of cognitive function and reported mood." Likewise, self-reported mood states were not considered, on average, a sensitive correlate of the measured physiological indicators of heat strain. In the present study, mood and symptoms questionnaire ratings, POMS mood category scores, and TLX scores also correlated poorly (<0.70), or not at all, with physiological responses such as maximum core temperature, sweating rates, and skin temperatures.

In another, relatively recent study, Thornton et al. (1992) evaluated the effects of heat stress on aviators wearing the aircrew uniform integrated battlefield (AUIB) MOPP4 ensemble. Nineteen aviators between 21 and 39 years of age participated in that study. It was conducted using both cool and hot cockpit conditions. The temperate condition had a dry bulb temperature of 21°C (70°F) with 50 percent RH resulting in a WBGT of 16.8°C (62.2°F) - heat stress category 0. The hot condition had a dry bulb temperature of 35°C (95°F) with 50 percent RH resulting in a WBGT of 29.4°C (84.9°F) -- the upper limit of heat stress category 2. Each 6-hour flight session in the USAARL UH-60 simulator was preceded by a 20-minute walk on a treadmill in a heated room on (~ 375 watt metabolic rate). That was done to simulate the exertional thermogenic effect of a routine UH-60 preflight inspection.

Compared to Thornton's study, this study used a shorter simulator flight scenario (4 hours) to alleviate the boredom associated with Thornton's 6-hour scenarios (used in earlier research). We also performed the same simulated preflight using two treadmills. However, we used an environmental chamber for the simulated preflight and therefore had better control over temperature and humidity. The average calculated metabolic rates for the pilot volunteers in this study (using 3 mph, 0 grade, and average undressed pilot weight of 78.8 kg) were 357 watts when wearing the unencumbered MOPP0 ABDU flight uniform (8.07 kg load) and 426 watts when wearing the encumbered MOPP4 ensemble (25.94 kg load).

In Thornton's 1992 heat stress study, when the volunteer aviators wore the MOPP4 AUIB in their hot condition (two WBGT heat stress categories less than ours), mean heat stress tolerance time was 298 minutes (almost 5 hours). One test subject withdrew after only 1 hour. Fifty percent of the test subjects were able to complete the entire 6-hour flight scenario. The ones with shorter tolerance times tended to be heavier, older, and had greater rates of sweating and dehydration. The latter suggests

that those with lower endurance times probably were well acclimated. However, increased sweating rates while wearing the occlusive AUIB MOPP4 ensemble did not provide a thermoregulatory advantage since most of the additional sweat did not evaporate and therefore contributed to dehydration but not cooling. The AUIB study data also indicated that the increased sweating rate was not matched with proportionally increased water intake. Dehydration can reduce tolerance time by causing reduced cardiovascular reserve and fatigue.

In our study, mean tolerance time in the MOPP4-100°F condition was 107 minutes with no statistically significant correlations between tolerance times and weight or age even though there was substantial variability in those measures.

In Thornton's 1992 study, core temperature increased significantly (1.8°C or 3.4°F) and heart rate rose consistently above 100 beats per minute only during the MOPP4 AUIB-95°F conditions. Mean skin temperature in the MOPP4 AUIB-95°F condition rose almost 2°C (3.6°F). Lesser elevations in skin temperature were noted for the MOPP4 AUIB in cool and MOPP0 standard flight uniform in hot conditions, in that order. Sweating rates varied from 90 cc/hr in the standard-cool condition to 600 cc/hr in the MOPP4 AUIB-95°F condition. By the end of the MOPP4 AUIB-95°F scenario, the test subjects had accumulated, on average, a 1 to 1.5 liter fluid intake deficit.

In the present study, core temperature in the encumbered MOPP4-100°F condition increased by the same amount (due to reaching the core temperature limit), but over a shorter period of time. Average maximum heart rate during the simulator sorties for the encumbered MOPP4 and the MOPP0 ABDU uniforms in the hot condition were 143 (range: 170-119) and 100 (range: 122-73) bpm, respectively. Weighted mean skin temperature for the MOPP4-hot condition rose to 101°F (approximately 11°F greater than for the baseline MOPP0-cool condition). Sweating rates in this study were also higher than those in the 1992 AUIB study. Our aviators sweated an average of 92 cc/hr in the baseline MOPP0-70°F condition and increased to 1523 cc/hr in the encumbered MOPP4-100°F condition. By the end of the MOPP4-100°F condition, the volunteer aviators had accumulated an average of 1.93 liters fluid intake deficit (2.45 percent dehydration).

In Thornton's 1992 study, questionnaire data indicated that the AUIB MOPP4-95°F condition evoked the greatest temporal progression of fatigue. Post-flight questionnaires regarding the fit and comfort of the flight ensembles showed that the aviators had difficulty drinking water and impaired visibility while wearing the M43 CB protective mask. Other problems reported by the study participants included bothersome encumbrance and restriction of movements due to the thickness of the AUIB MOPP4 ensemble in conjunction with the SARVIP and ballistic protection plates.

Results from this study revealed similar findings. POMS questionnaire data showed significant effects for both temperature and uniform with greater fatigue scores for the 100°F condition and the encumbered MOPP4 ensemble. Ratings on the mood and

symptoms questionnaire showed only a uniform effect, with higher ratings for visual difficulty in the encumbered MOPP4 ensemble when the aviators were wearing the M43A1 CB mask.

Conclusions

In the hot condition (100°F, 50% RH, and overhead bank of heat lamps to partially simulate solar radiation), the current 2-piece ABDU and SARVIP with BDO and other MOPP4 components additionally encumbered with ballistic protective chest plate and overwater survival gear compared to the unencumbered MOPP0 ABDU flight uniform significantly decreased mission endurance from the fully completed mission time of 309 minutes (range: 347-288) to 107 minutes (range: 154-40). This was due to increases in core temperature (0.73°F/hour), physical discomfort, psychological stress, and adversely affected mood. Heavy sweat rates (1523 cc/hour) lead to greater amounts of dehydration (2.25 percent) which added to the discomfort. The encumbered MOPP4 ensemble was consistently rated as uncomfortable and cumbersome. Mask and helmet pressure points were prevalent, and the heavy ballistic protective vest caused stress on the shoulders while ambulating. Many of the aviators had difficulty maintaining the mask eyepieces properly centered over their eyes. The encumbrance and thickness of the ensemble, in some cases, also restricted the range of cyclic movements (particularly aft) while on the controls in the UH-60 simulator.

Based on these results we recommend that the various components of the encumbered MOPP4 ensemble be modified to be lighter weight and more permeable to sweat. The ballistic protective plate, in particular, should be lighter weight and reduced in thickness if at all possible. An alternative would be to modify the ballistic plate in such a manner as to prevent it from resting directly on the chest. This would help maintain the chest-clothing air space thereby improving convective heat transfer and evaporation of sweat from that critical area. Methods should also be sought to improve fit and comfort for the mask and helmet as well as to prevent discomfort over the back due to pressure from the life raft. A pilot controllable microclimate cooling system, e.g., using forced dry cooled air directed into the encumbered MOPP4 ensemble, should be considered for reducing heat accumulation and increase endurance when wearing the MOPP4 ensemble during hot weather operations. See Pandolf, et. al (1995) for a recent review of general issues and performance capabilities (e.g., nominal cooling rates) of alternative microclimate cooling systems.

References

ATCOM. 1995. Operational Requirements Document for the Air Warrior (draft). St. Louis, MO.: Aviation and Troop Command.

Allan, J.R., and Wilson, C.G. 1971. Influence of acclimatization on sweat sodium concentration. Journal of Applied Physiology. 30(5): 708-712.

Breckenridge, J.R., and Levell. 1970. Heat stress in the cockpit of the AH-1G Hueycobra helicopter. Aerospace Medicine. 41(6):621-626.

Bruckart, J.E., Licina J.R., Olding B., and Quattlebaum, M. 1992. Test and evaluation report of the Human Technology Ambulatory CorTemp Recorder model COR-124. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-19.

Carter, K.B. 1986. Clinical temperature measurement. In: Physics in Medicine and Biology Encyclopedia. (Ed: McAinsh, TF). NY, NY: Pergamon Press.

Christensen, L.B. 1985. Experimental Methodology. Newton, MA: Allyn and Bacon, Inc.

Considine, D.M., and Considine, D.M. 1983. Climate. In: Van Nostrand's Scientific Encyclopedia (6th edition). NY, NY: Van Nostrand Reinhold Co.

Epstein, Y., Strochein, L.A., and K.B. Pandolf. 1987. Predicting Rectal Temperature Response to Work, Environment, and Clothing. European Journal of Applied Physiology. 56: 495-500.

Gonzalez, R.R. 1988. Biophysics of heat transfer and clothing considerations. In: Human Performance Physiology and Environmental Extremes (Eds: Pandolf, K.B., Sawka, M.N., and Gonzalez, R.R.). Indianapolis, IN: Benchmark Press, Inc.

Hart S.G., and Staveland, L.E. 1988. Development of NASA-TLX (Task Load Index): Results of Emperical and Theoretical Research. In Eds. P.A. Hancock and N. Meshkati. Human Mental Workload. Amsterdam: North Holland Press.

HTI. 1991. CorTemp temperature monitoring system operating instructions. St. Petersburg, FL: HTI Technologies, COR-03/91.

Hudson. 1969. Infrared System Engineering. New York: John Wiley and Sons.

Kerstein, M., Hubbard, R., Mager, M., and Connely, J. 1984. Heat-related problems in the desert: the environment can be an enemy. Military Medicine, 149, 12:650.

Knox III, F.S., Nagel G.A., Hamilton B.E., Olazabel R.P., and Kimbal K.A. 1982. Physiological impact of wearing aircrew chemical defense protective ensembles while flying the UH-1H during hot weather. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 83-4.

McNair, D., Lorr, M., and Droppleman, L. 1981. Edits Manual for the POMS: Profile of Mood States. San Diego, California: Educational and Industrial Testing Service.

Mitchell G.W. 1991. Rapid onset of severe heat illness: a case report. Aviation Space Environmental Medicine. 62: 779-82.

Human Performance Research Group. NASA Task Load Index (TLX) (Vol 1.0). Moffett Field, California: NASA Ames Research Center.

Pandolf, K.B., Burse, R.L., and Goldman, R.F. 1977. Role of physical fitness in heat acclimatization decay and reinduction. Ergonomics. 20:4, 399-408.

Pandolf, K.B., Gonzalez, J.A., and Sawka, M.N. 1995. An Updated Review: Microclimate Cooling of Protective Overgarments in the Heat. Natick, MA: U.S. Army Research Institute of Environmental Medicine, Technical Report T95-7.

Ramanthan, N.L. 1964. A new weighting system for mean surface temperature. Journal of Applied Physiology. 19:531-533.

Ryan, S.M. 1993. Aircrew survival armor recovery vest. U.S. Army Aviation Digest. 93(1): 52-53.

Sawka, M.N., and Wenger, C.B. 1988. Physiological responses to acute exercise-heat stress. Human Performance Physiology and Environmental Extremes (Eds: Pandolf, K.B., Sawka, M.N., and Gonzalez, R.R.). Indianapolis, IN: Benchmark Press, Inc.

Schlesinger, M.J. and Collier, N.C. 1991. Heat shock. In: Encyclopedia of Human Biology, Vol. 4. NY, NY: Academic Press.

Stephenson, L.A., Quigley, M.D., Blanchard, L.A., Toyota, D.A., and Kolka, M.A. 1992. Validation of two temperature pill telemetry systems in humans during moderate and strenuous exercise. Natick, MA: U.S. Army Research Institute of Environmental Medicine, Technical Report T10-92.

Thorton, R., Brown, G.A., and Higenbottam, C. 1984. The energy expenditure of helicopter pilots. Aviation Space Environmental Medicine. 55:746-50.

Thorton, R., Caldwell, J.L., Clark, W., Guardiani, F. and Rosario, J. 1992. Effects on physiology and performance of wearing the aviator NBC ensemble while flying the UH-60 helicopter flight simulator in a controlled heat environment. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-36.

Thorton, R., and Guardiani, F. 1992. The Relationship between environmental conditions and UH-60 cockpit temperature. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-25.

USAAC. 1989. Blackhawk UH-60A Mission profiles and operational mode summaries (MP/OMS). Fort Rucker, AL: U.S. Army Aviation Center.

USAARL. 1995. Statement of work for evaluation process (EP) support Air Warrior concept exploration. Fort Rucker AL: U.S. Army Aeromedical Research Laboratory.

Wenger, C.B. 1988. Human heat acclimatization. In: Human performance physiology and environmental extremes (Eds: Pandolf, K.B., Sawka, M.N., and Gonzalez, R.R.). Indianapolis, IN: Benchmark Press, Inc.

Wentworth, S.L., McGowin, III E., Ivey, R.H., Rash, C.E., and McLean, W.E. 1995. Transmittance characteristics of U.S. Army rotary-wing aircraft transparencies. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 95-19.

Wyndham, C.H. 1973. The physiology of exercise under heat stress. Annual Review of Physiology, 35:193-220.

Appendix A. Data Tables

Table A-1.
Demographics.

Test Subjects	RANK	GENDER	HAVE YOU EVER BEEN A TEST SUBJECT IN OTHER STUDIES	WHAT AIRCRAFT ARE YOU RATED IN	ADDITIONAL AVIATOR QUALIFICATIONS	TOTAL FLIGHT HOURS AS A PILOT	UH-60 PILOT FLIGHT HOURS	UH-60 SIMULATOR PILOT HOURS	NBC OVERGARMENT AND MASK PAST YEAR (HRS)
1	MAJ	FEMALE	YES	UH-1, UH-60	FW MULTI-ENGINE	1100	500	100	0
2	CW4	MALE	NO	UH-60	UH-1, OH-58	2800	40	8	0
3	CW3	MALE	NO	UH-1, OH-58, TH-55, AH-1, UH-60	N/A	2200	300	40	1
4	1LT	MALE	NO	UH-1, OH-58	N/A	320	0	8	0
5	CW3	MALE	NO	UH-1 H & M, AH-1	N/A	1750	0	2	1
6	WO1	MALE	NO	UH-1, UH-60	N/A	200	17	9	0
7	CW2	MALE	NO	UH-60, UH-1	N/A	695	530	45	1
8	CW2	MALE	NO	UH-60, UH-1	N/A	630	540	90	2
9	CW3	MALE	NO	TH-55, UH-1, OH-58, UH-60	SEL PRIVATE PILOT	4000	120	40	3
10	MAJ	MALE	NO	AH-1, OH-58, UH-1	IP, NVG IP	1500	0	0	0
11	CW2	FEMALE	YES	153D, UH-60A	UH-1H	450	25	20	0
12	CW3	MALE	NO	UH-60, UH-1	N/A	2300	1800	160	0
13	CW3	MALE	YES	UH-60, UH-1, OH-58	MTP ALL THREE A/C	1800	1500	300	0
14	CW2	MALE	YES	UH-1, UH-60	MEDEVAC	600	500	150	1

Table A-1. (continued)

Demographics.

Test Subjects	NBC OVERGARMENT AND MASK PAST 5 YEARS (HRS)	AGE	HEIGHT (INCHES)	WEIGHT (POUNDS)	MOST RECENT PT TEST	PUSHUPS	SITUPS	RUN TIME	ESTIMATE OF PERCENTAGE OF MAXIMUM EFFORT (0-100%)	HOW MANY TIMES PER WEEK YOU DO PT	TOTAL HOURS OF PHYSICAL TRAINING PER WEEK	TOTAL HRS TRAINING IN HEAT CASUALTY OVER PAST TWO YEARS
1	0	36	67	134	6/1/95	35	65	19:00	100	3	3	0
2	0	49	70	170	10/1/95	30	30	16:30	80	1	1	0
3	5	33	69	155	11/1/95	55	55	14:30	90	4	4	3
4	1	29	71	175	12/15/95	67	92	12:10	100	6	6	1
5	7	50	68	192	4/13/96	37	31	18:35	90	3	3	0
6	0	28	71	170	3/1/96	65	88	1430	85	4	4	0
7	3	31	74	190	4/1/96	50	47	16:24	85	3	3	1
8	8	32	71	198	5/1/96	40	45	15:38	70	3	3	0
9	18	32	72	178	2/1/96	46	56	15:10	100	2	2	6
10	4	44	71	175	5/10/96	75	80	14:20	100	3	3	0
11	5	32	65	142	4/1/96	48	81	17:30	90	7	10.5	3
12	4	34	67	165	7/1/96	75	64	14:10	70	3	3	0
13	52	41	68	175	11/1/95	80	80	13:20	100	5	5	0
14	5	27	70	155	4/1/96	60	70	15:00	90	3	4.5	4

Table A-2.

Heart rate and core temperature maximums.

	ABDU 70°F		MOPP4 70°F		ABDU 100°F		MOPP4 100°F	
Test Subject	Heart Rate	Core Temperature	Heart Rate	Core Temperature	Heart Rate	Core Temperature	Heart Rate	Core Temperature
1	119	99.824	104.2	99.59	120	100.346	134.7	102.2
2	99	99.05	86.5	99.572	107.2	99.7	138	102.254
3	112	99.32	169	99.86	135	99.86	177	102.56
4	114	98.96	142	99.68	122	99.86	147	101.48
5	108	98.78	129	99.32	120	99.14	154	102.56
6	119	98.96	116	99.5	127.5	100.04	163	101.12
7	130	100.22	103.8	100.76	101.1	102.2	168	100.94
8	92	99.5	127	99.86	111	100.76	120	102.2
9	108	99.14	150	100.04	135.3	101.12	153.5	101.48
10	96	99.32	106	99.68	94	99.5	132	102.56
11	105	98.96	134	100.04	123	99.68	144.5	100.58
12	100	98.42	130	98.96	122	99.5	148	101.12
13	98	100.22	104	98.42	106	99.86	133	102.326
14	136	99.5	125	99.86	114.5	99.68	149	101.966
15	96.1	98.96	112	100.04	107.3	99.5	161.8	102.614
16	91	98.8	114	99.32	108.3	98.96	150	102.56
17	94	99.86	115	100.22	103	99.86	176.3	102.38

Table A-3.

Calculated metabolic rate during preflight simulation (in watts).

CALCULATED METABOLIC RATE DURING PREFLIGHT SIMULATION (in Watts)				
TEST SUBJECT	**ABDU, 70**	**ABDU, 100**	**MOPP4, 70**	**MOPP4,100**
1	279.1211	282.8556	357.4602	359.7582
2	360.0424	360.0424	429.5401	426.6541
3	314.8527	311.5250	384.7543	387.8989
4	384.4420	376.7238	445.6079	443.0809
5	373.3867	372.3440	439.2004	442.1099
7	403.0147	401.5536	466.7321	465.5529
8	350.4552	349.2050	419.3697	422.6236
9	392.5795	394.4576	463.0000	456.7291
10	409.6948	410.7386	479.3478	477.5697
11	362.1270	358.7917	428.3850	431.0817
12	358.7917	356.4989	424.9253	423.5822
13	359.0001	357.7494	425.5013	427.8078
14	366.0882	363.3778	435.9092	436.6830
15	303.6246	306.1190	379.6033	375.9467
16	337.7477	336.2900	407.9533	405.8726
17	365.2542	372.7611	434.3628	435.1358
AVERAGE	**357.5139**	**356.9396**	**426.3533**	**426.1304**
STANDARD DEV	**35.0949**	**34.4931**	**32.1867**	**31.3195**
STANDARD ERROR	**8.5118**	**8.3658**	**7.8064**	**7.5961**

Table A-4.

Maximum and minimum skin temperatures.

	ABDU, 70°F								MOPP4, 70°F							
Test Subject	ARM		CHEST		THIGH		LEG		ARM		CHEST		THIGH		LEG	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
1	34.12	33.04	39.86	36.55	31.52	30.99	33.94	31.74	36.57	35.08	37.28	36.9	34.72	33.72	34.52	31.82
2	32.47	30.96	35.3	33.79	30.96	29.96	33.32	31.81	37.16	36.79	36.44	35.74	34.95	33.43	34.26	32.53
3	34.32	32.2	36.9	35.93	33.75	32.25	33.21	32.06	36.43	34.93	37.06	36.86	36.15	34.03	34.02	31.29
4	32.53	31.44	34.65	31.78	32.66	31.07	32.91	30.9	37.48	36.97	36.79	34.77	36.34	31.95	34.17	30.62
5	34.22	32.66	35.42	33.69	32.61	30.99	32.18	30.13	35.74	32.64	36.82	36.24	35.26	33.15	34.11	30.76
6	37.34	36.78	32.47	29.96	30.22	29.96	33.34	30.53	37.76	37.15	36.82	36.31	36.06	30.07	35.13	30.74
7	34.3	32.44	36.63	35.05	31.7	30.91	33.27	31.78	36.45	32.52	37.85	37.08	36.89	33.53	34.65	30.81
8	37.4	36.82	35.2	34.16	30.46	29.96	32.42	30.46	37.5	36.9	36.96	35.32	34.77	31.27	34.46	29.86
9	33.73	31.3	36.59	34.5	32.56	31.31	33.06	31.9	35.96	33.77	37.36	36.97	36.05	33.94	34.8	33.13
10	37.17	36.72	35.05	33.22	31.89	29.96	32.85	31.5	37.42	36.57	36.79	34.61	35.21	31.56	32.22	29.86
11	32.93	31.46	36.05	33.75	32.99	31.64	32.7	32.08	35.79	33.26	36.67	35.81	35.06	33.28	32.97	30.88
12	36.83	36.47	34.68	32.52	32.05	29.96	31.65	30.79	35.38	31.9	35.98	35.25	34.55	32.15	33.64	31.13
13	33.31	30.91	35.73	33.73	31.56	29.94	31.4	29.87	34.99	32.43	36.3	35.82	34.22	30.09	34.97	32.46
14	37.43	37.04	36.72	35.97	31.56	29.96	32.77	29.86	36.42	32.36	37.15	36.3	35.59	31.11	33.63	30.96
15	33.83	32.9	36.69	34.28	32.59	31.28	33.12	31.69	36.08	32.22	37.44	36.66	35.77	32.63	34.1	30.66
16	37.08	36.81	35.64	33.53	32.24	31.26	30.99	29.86	35.75	32.68	36.81	35.92	35.1	31.68	32.92	30.24
17	32.65	31.69	36.23	35.23	31.67	30.49	33.99	32.05	35	32.92	37.05	36.24	33.16	31.76	34.33	32.87
AVG	**34.80**	**33.63**	**35.87**	**33.98**	**31.94**	**30.70**	**32.77**	**31.12**	**36.35**	**34.18**	**36.92**	**36.05**	**35.29**	**32.31**	**34.05**	**31.21**
SD	**1.93**	**2.47**	**1.50**	**1.61**	**0.90**	**0.73**	**0.83**	**0.86**	**0.88**	**1.99**	**0.45**	**0.75**	**0.90**	**1.27**	**0.77**	**1.00**
SE	**0.36**	**0.47**	**0.28**	**0.30**	**0.17**	**0.14**	**0.16**	**0.16**	**0.17**	**0.39**	**0.09**	**0.15**	**0.18**	**0.25**	**0.15**	**0.20**

	ABDU, 100°F								MOPP4, 100°F							
Test Subject	ARM		CHEST		THIGH		LEG		ARM		CHEST		THIGH		LEG	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
1	37.51	36.01	37.64	36.07	36.98	34.46	37.16	35.25	38.65	38	38.51	37.79	38.66	37.79	37.47	36.92
2	37.04	35.49	36.79	35.46	36.92	35.69	36.6	35.49	38.75	37.73	38.96	37.8	38.89	37.79	37.85	37.21
3	37.04	35.6	37.4	36.44	37.18	35.47	36.92	35	38.8	37.97	38.57	37.83	38.76	37.92	37.35	36.65
4	37.12	35.81	36.87	35.63	37.05	35.92	36.23	34.45	38.22	37.46	38.04	37.2	38.23	37.52	37.28	36.82
5	36.27	35.35	37.28	36.46	36.91	36.19	35.94	34.13	38.6	37.35	38.72	37.66	38.69	37.06	37.85	36.92
6	37	35.02	36.71	34.5	36.41	34.4	36.58	32.97	38.18	37.53	38.06	37.27	37.44	36.88	38.17	37.33
7	36.12	35.51	37.38	36.3	36.29	34.61	36.23	34.75	38.68	38.1	38.96	38.4	38.89	38.36	37.65	37.37
8	37.46	36.24	37.2	35.92	37.1	34.43	37.12	35.22	38.4	37.92	38.55	38	38.3	37.79	37.8	37.48
9	37.73	36.36	38.05	37.05	37.54	36.18	37.68	35.03	38.3	37.73	39.86	38.06	38.54	38.05	37.64	37.15
10	36.53	35.1	36.28	34.16	35.26	33.83	35.6	31.74	38.59	37.67	38.84	37.67	38.88	37.93	37.63	37.2
11	36.8	35.85	37.19	35.11	36.38	34.81	35.81	33.48	37.7	37.63	37.96	37.82	37.84	37.64	36.73	36.42
12	37.08	35.65	36.65	34.53	36.74	34.91	36.16	34.16	38.15	37.32	38.25	37.35	38.36	37.58	37.1	36.67
13	36.12	34.55	37.06	35.8	34.79	33.12	34.93	33.57	38.68	37.24	38.84	37.63	38.5	37.13	37.86	36.71
14	37.41	35.49	37.35	36.08	36.88	35.31	37.3	34.6	38.48	37.96	38.58	37.95	38.54	37.9	37.54	37.13
15	36.3	34.17	37.43	36.5	36.13	34.57	36.26	34.96	38.68	37.92	38.74	38.01	38.74	38	37.76	37.24
16	35.71	34.37	36.58	35.04	35.55	34.05	34.89	32.77	38.7	37.32	38.61	37.32	38.72	37.51	38.03	36.46
17	37.02	34.88	37.55	36.22	36.51	34.84	36.61	34.85	38.24	37.1	38.66	37.64	37.45	36.29	37.69	36.8
AVG	**36.84**	**35.38**	**37.14**	**35.72**	**36.51**	**34.87**	**36.35**	**34.26**	**38.46**	**37.64**	**38.63**	**37.73**	**38.44**	**37.60**	**37.61**	**36.97**
SD	**0.57**	**0.63**	**0.45**	**0.81**	**0.73**	**0.84**	**0.78**	**1.03**	**0.32**	**0.26**	**0.53**	**0.34**	**0.45**	**0.41**	**0.39**	**0.33**
SE	**0.11**	**0.12**	**0.09**	**0.16**	**0.14**	**0.17**	**0.15**	**0.20**	**0.09**	**0.07**	**0.15**	**0.10**	**0.13**	**0.12**	**0.11**	**0.10**

Table A-5.
Test subject heart rate data.

	ABDU, 70°F																
TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
0	87.5	74.2	95.3	89.8	81	87.3	72.2	70.9	100.8	76.2	80.5	72.9	67.2	79.1	90.1	87	85.2
10	86.5	77.3	63.5	75.2	73	90.3	74	73.5	82.3	77.6	78.2	78	68.2	79.3	81	83	84.5
20	87.8	69.9	86.4	82.4	60	87.5	87.4	67.8	84	70.2	77	76.4	63	66.5	70.9	82	82.6
30	91.3	79.3	101.2	72.3	82.5	88.6	76.4	69.5	83.5	74.9	69.8	86	66	67.3	65.3	91	84.2
40	88	71.4	92	76.4	65.2	80.1	78	67.3	84.2	68.3	74.8	70.2	65.8	80.8	68.8	79	85.3
50	89.7	66.5	97.3	66.5	65.2	83.6	68.3	72.3	89.3	71.3	79.5	75.5	66.8	67.3	68	80	87.5
60	88.3	72.8	90	68.3	63.8	84.2	86.6	65.8	88.8	67	70.3	66.8	66.7	68	76	91	89.6
70	87.8	70.8	95.8	60	60	86.2	72.8	68.3	83	67.2	78.7	74.4	63.6	66	70.2	86	70.8
80	88.4	67.7	105	78.6	59.7	91.8	60.7	65.3	78.8	66.3	68.9	65.6	63.2	76.3	69.8	75	85
90	88.6	69.9	98	69	60	88.8	68	71.4	82	71	72.8	71.3	66.8	59.8	67.8	71	84.3
100	89.2	71.8	96	62.5	60	89.2	74.6	68.8	80	61.2	67.8	66	66.8	61	63.5	75	81.8
110	82.3	71.1	101	66.8	60	87	88.5	64.2	84.3	57.2	74.2	77.5	63.8	59.3	69.9	85	74.8
120	91.2	67	97	59	60	86.5	72	60.3	91.3	67.5	77.3	68.8	62.3	66.7	87.8	72	86.5
130	90.8	66.9	98.3	66	60	81	81.5	68.4	86	65.2	74.2	71.8	62	74.4	75.4	70	85.8
140	87	69.5	87	65.5	64.9	85.7	82.5	67.5	85.3	64	86.2	70.3	76.2	63.5	67.5	75	87.6
150	88.6	65.5	90	56.2	61.2	88.2	56.7	66.8	88.8	65	72.4	73.5	64.6	69.5	78.5	73.5	81.3
160	98.6	71.5	93	59	60	83.5	68.2	65.4	89.9	65	88	78.8	65.4	67.3	83.3	69.9	72
170	94.5	69.2	92	53	62	83.5	68.3	70.8	87.4	67.5	89.5	90.4	64.3	69.5	74.6	71	89.2
180	97.8	71	103	59.1	60	81.5	76.6	72.9	93.8	66.8	80.8	71.2	69.8	69.3	71.8	75.8	70.3
190	98	68.7	95	58.5	60	82.8	71.3	78.3	90.3	69.3	88.5	84.8	69.9	87.2	72	79.8	78.7
200	98.2	65.2	97	61.2	60	87.7	70.8	71.1	91.8	66.6	90.3	82.3	69.3	77.2	77	79.8	78.8
210	93.3	67.5	90	55.2	60	86.3	77.4	76.4	91	64.8	82.4	73.8	70.5	72.6	72.8	72.8	76.8
220	87.6	69.6	90	59.1	60	92.8	74	77.9	94	68.2	87.6	84.5	69.5	81.5	75.2	78.3	72.8
230	84.5	66.5	100	84	62.5	93.2	72	72.3	90.3	65.2	92.3	81.9	80	71	73.8	78.3	70.7
240	88.4	67.5	100	70	60	88.5	78.2	72.8	99.1	72.2	90	78.6	63	70.5	76.8	78.1	71.8
250	93.4	64.7	90	55.2	62.5	87.5	85	74.2	89.3	67.8	94.4	76.5	63	71.2	73.2	80.8	75.8
260	88.8	69.4	105	78	60	86.3	87.4	75.5	98.8							77	77.6
270																	
AVG	91.188889	69.72	95.07	66.18	62.34	86.58	70.49	70.21	89.07	67.83	79.17	75.68	66.83	70.77	73.30	78.41	69.70
SD	4.38	3.45	7.75	9.25	4.71	3.37	5.72	4.33	6.14	4.39	8.48	6.47	4.22	7.04	6.60	5.99	5.73
SE	0.83	0.65	1.46	1.75	0.89	0.64	1.08	0.82	1.16	0.83	1.60	1.22	0.80	1.33	1.25	1.13	1.08

	ABDU, 100°F																
TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
0	100.9	72.8	120	82.8	83.7	109.3	88.9	74.2	91.6	76.2	98.8	88.9	83.9	67.3	76	108.3	78.8
10	96.5	77.8	103	84.5	101.2	99.3	74.5	73.3	93.8	77.7	88.3	80.3	82.3	70	81	88.8	77.3
20	99.8	71.7	96	90	90.4	109.8	78.4	91.8	97.4	75.2	79.8	83.2	81.5	71.3	77.5	92.5	81.6
30	97.5	73.8	100	89.2	84.8	104.6	79.2	74.5	99.2	59.3	82	82.8	85.8	73.4	71.5	90	77.5
40	96.6	74.2	108	89.2	93.8	103.9	80.9	77.2	100.8	75	96.8	84.2	82.8	85.4	83.5	96.5	81
50	94.1	79.2	96	86.5	92.8	102.8	88.3	75.8	98.6	76	91	87.4	80.3	77.5	72.9	96.3	78.8
60	95.5	107.2	98	83.5	94.3	107.5	88.5	79.5	98.3	81	91.8	94.5	87.8	81	87.9	96.8	81
70	101.5	78.8	100	88.3	91.7	111.2	88	78	97.2	70	101.8	90.8	73.5	91.5	72	92.5	86
80	97.8	75.5	96	90.7	96.2	108.6	81.9	85.5	99.8	75	91.6	93.2	77.6	92.5	84.8	91.8	78.8
90	98.4	77.8	92	79.9	88.7	103.9	85.5	73	98.7	76	93.8	93.2	80.5	92.1	94	93	93.6
100	101	78.8	105	85.5	92.2	104	87	82.2	102.3	71	85	86.8	77	85.3	103.5	85.8	86.3
110	106.5	77.1	100	92.7	88	106.3	77.3	72.9	109.3	72	92.5	85.3	74.9	88.8	92	88.9	91
120	109.8	75.5	105	80	98.4	104.4	84.9	83.5	107.4	75	99.6	89.5	77.8	92.8	91	89	83.7
130	99.8	81.7	120	84.2	90	100.8	80	82.5	106.9	80	93.3	83.5	86.3	113	104	76.3	83.0
140	100.8	72.9	105	93	88	100.3	90.4	86.2	107.6	74	100	87.8	84.9	101.2	85.5	89.9	83.7
150	106.3	76.5	120	94.5	90	117.4	89	68.2	108.3	75	97	94.8	78	80.8	86.4	85.8	86.5
160	100.8	76.5	120	95.8	90	117.2	90.6	91.2	122.9	88.5	105	94.8	79	114.5	96.5	95.9	90.8
170	108.2	82.2	106	89.5	90	117.1	87.8	95.5	128.3	82.3	97	101.2	74	83.4	88.6	89.3	94.5
180	102.5	81.4	127	95	90	121.6	101.1	103.9	125.2	77.3	104.2	109.3	71.3	87.5	85.6	92.8	97.4
190	110	87.5	127	96.5	97	122.3	90	95.5	128.7	84.8	105	115	78	99.8	80.2	90.1	86.1
200	104.4	85.7	139	110.5	90	120	94	99.4	120.8	83.5	101	107	76	92.6	81.6	95.2	103
210	101.4	83.5	120	94.8	97	115	95	101.5	127.9	78	102	109.3	74	91.4	80	92.3	100.9
220	105.2	84.3	127	98.2	97	115.4	100.1	94.2	120.1	75.2	108	112.8	78	88.2	91.3	88.8	95
230	105.3	81.2	135	93.5	97	116.5	97.4	98.3	120.5	88.8	104	117	72	92.6	107.3	90	94
240	101.2	81.5	135	102.9	97	119.5	77	103.2	125.6	91	98	106	74	90.8	92.8	81.5	94.2
250	109.1	87.5	136	99.5	98	122.6	81.2	99.3	139.8		110.9	122	71	92.3	96.4	85.8	101.5
260		88.3			90	124.3	92.3							95	80		
270					105	127.5	90										
AVG	101.85	80.40	112.62	91.18	97.00	111.90	87.33	86.55	110.69	77.51	96.75	96.16	77.10	88.59	83.85	90.84	88.27
SD	4.44	7.13	14.49	7.15	4.71	8.25	7.27	11.18	14.47	6.70	7.71	12.20	8.25	11.31	12.34	5.90	8.14
SE	0.84	1.35	2.74	1.35	0.89	1.56	1.37	2.11	2.73	1.27	1.46	2.31	1.18	2.14	2.33	1.12	1.54

Table A-5.(continued)

Test subject heart rate data.

	MOPP IV, 70°F																
TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
0	99.8	84.2	158.3	113.5	73.6	142.4	144.3	90.2	118.1	96.5	124.8	86.5	70.4	104.5	98.4	101.8	100
10	95	77.3	130	96.8	81.5	126.8	139.8	89.3	116.3	80.9	100.4	84.5	69.2	83.8	90	96.3	81.5
20	98.6	75.5	113.4	116	76.3	123.5	121.8	82.4	102.9	75.2	90.2	80.6	72.8	85.4	79	96.4	76.3
30	91.5	75.8	116.1	88.2	72	119.7	111.3	84.9	107.5	72.9	89.3	71.2	71.7	78	96	93	77.8
40	96.5	74.5	105.5	85.2	74.6	115.3	103.8	84.5	95.7	69.8	89.3	79.4	70.6	84	91	90	77
50	91.6	80.5	107.8	85.7	70.4	109.9	91.8	81.9	102.6	71.7	87.2	73.2	63.6	80.8	83	89.8	84.2
60	88.2	70.5	104.3	81.3	88	116	97.2	76.5	96.2	70.4	98.2	73.9	58.2	74.5	77	89.8	72.3
70	90.2	68.7	108.4	82.6	70.1	110.9	83.1	82	95.4	69	95	79.5	59.2	86.8	77	90	75.3
80	91.6	68.5	104.1	86.7	64.5	102.5	87	77.2	90.6	68.8	80.8	68.9	64.3	76.8	81	80.1	79.9
90	89.7	72.8	104.5	78.3	86.5	107.8	77.2	76.5	91.0	74.3	78.8	69.8	65.2	73.4	88	81.5	74.3
100	92.2	70.5	104.3	75.2	62.2	103	86.4	75.3	99.6	71.2	79.9	69.5	68.6	72.9	73	82	71
110	90.8	70.4	101.1	74.5	65.6	113.9	89.3	74.2	93	69.5	84.9	67.5	54.4	71.3	78	78.3	84.6
120	90.8	68.8	98.3	84	84.8	114.2	98.3	66.5	107.3	65.2	78.2	74.9	64.2	76.5	70	91.8	77.3
130	92.5	77.5	97.5	71.3	81	108.8	98.9	72	71.8	65.7	90.3	83.5	69.6	76.4	73	88.8	73.6
140	93.7	86.5	99	80.5	58.3	113.5	97.5	76.3	103.7	66.3	73.6	71.4	61.1	76.8	76	74.3	77.8
150	96.5	67	101.6	70.5	68.3	106.3	78.5	75.8	106.3	62.8	81.5	71	60	83.1	77	75.5	78.2
160	95.8	73	107.6	70.3	83	115.5	78	89	106.4	64.2	72.8	70.2	60	88.8	69	88.3	84.6
170	93.6	72.5	109.2	73.5	70	104.3	91.2	74.8	103	58.9	84.9	72.8	57.6	75.8	75	77.1	83.4
180	92.6	75.2	108.1	77.5	71.6	114	88.6	89.8	106.6	62.5	80.1	77.4	59.7	81.8	73	75.2	86.7
190	96.8	74.5	108.1	72	73.6	114.5	80.2	109.2	106.7	63.6	82.5	78.8	70	85.5	81	78.9	87.3
200	92.6	75.3	106.2	61.8	63.6	109.8	85.9	76.8	104.8	65.7	83.3	73.2	80.9	77.2	72	79	77.6
210	94.5	73.7	105.4	68.3	66.3	111	93.5	79	98.4	69	78.8	83.5	84.3	94.5	70	84.3	85.3
220	91.6	82	111	70.5	74.3	108.5	85.4	77	97.8	78.2	90	92.1	78.4	76.3	81	77.9	80
230	95.4	81.5	112.5	70.8	65.2	106.8	89.9	77.8	90.7	67.3	83.2	74.5	68.6	76.5	81	87.1	81.4
240	104.2	76.8	104.8	68.7	71.6	107.6	79.7	79	92.9	63.3	80.9	83.7	62	74.3	83	78.4	84.6
250	90.8	76.7	111.5	67.7	73.4	106.8	79.3	84	123.3	67.8	84.3	90.2	62	78.2	92	80	89.8
260	92.3	78.7	109.9	69		105.2	82.3			65.3	78.8	86.9	60			99.8	103.2
270		79.8	107.9	64						66.3	88.3						
			103.5	65.2						78.3	97.3						
AVG	93.27	74.98	108.89	78.26	68.72	112.54	94.37	80.84	101.51	69.88	86.59	77.36	64.13	80.53	80.59	85.24	80.82
SD	3.45	4.69	11.32	13.03	5.35	8.37	17.21	8.23	10.06	7.29	10.14	7.01	6.15	7.39	8.08	7.99	7.72
SE	0.65	0.89	2.14	2.46	1.01	1.58	3.25	1.56	1.90	1.38	1.92	1.33	1.16	1.40	1.53	1.51	1.46

	MOPP IV, 100°F																
TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
0	128	108.5	155	124.4	120	138	168	107.2	143.1	106	142	129.3	105	124.3	128.8	123.9	125
10	134.7	111.5	150	116.9	112	145	164	113.2	138	120	144.5	127.3	105	119	139.7	116.5	122.8
20	127.6	114.5	165	126	105	152.5	163	116.5	144.6	113.9		125.5	105	118.4	139.9	122	138.6
30	120.6	125.5	165	129	112	147	144.5	118.5	150.8	120.4		127.2	106	120.8	141.8	126.4	136.5
40	122.2	119.5	170	133.5	120	155	148.2	117.9	146.3	125.5		130.2	120	115.5	150.8	132.8	145
50	120.5	127.6	170	135	120	154.3	160.7	113.8	159.5	123.5		139.2	120	124.6	156.2	134	164
60	123.9	122.3	170		127		161.9					133.8	118	132.3	161.8	143	143
70	120.3		170		135		153.9						112.5	133	155.5	135.8	141.5
80	108.65				155								112.5			133.4	145.4
90					127								120			137	156.1
100					135								120			148	164.6
110					136								133			150	178.3
120																	164
130																	
140																	
150																	
160																	
170																	
180																	
190																	
200																	
210																	
220																	
230																	
240																	
250																	
260																	
270																	
AVG	122.28	118.49	164.38	127.47	123.58	148.63	157.95	114.52	148.03	118.22	143.25	130.36	114.67	123.24	146.78	133.57	147.28
SD	7.37	7.21	7.76	6.61	10.43	6.58	8.31	4.17	5.55	7.17	1.77	4.73	8.76	6.66	11.02	10.25	15.42
SE	1.39	1.36	1.47	1.25	1.97	1.24	1.57	0.79	1.05	1.35	0.33	0.89	1.66	1.26	2.08	1.94	2.91

Table A-6.
Test subject core temperature data.

	ABDU, 70°F																
TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
0	99.5	99.0	99.32	99.374	99.14	99.32	98.24	99.5	98.96	98.96	98.96	98.42	98.4	99.5	98.96	98.78	98.78
10	99.4	98.9	99.14	99.32	98.96	99.14	98.96	99.32	99.14	98.96	98.96	98.24	100.22	99.5	98.6	98.78	98.42
20	99.2	98.8	98.96	99.32	98.906	99.14	98.96	99.32	98.96	98.96	98.78	98.06	98.42	99.5	98.42	98.78	98.42
30	99.1	98.7	98.78	99.14	98.78	98.96	93.02	98.96	98.96	98.96	98.78	98.06	98.24	99.32	98.42	98.6	98.24
40	99.1	98.7	98.78	98.96	98.6	98.96	98.42	98.96	98.78	98.78	98.6	97.7	97.88	99.14	98.24	98.6	98.24
50	99.0	98.7	98.6	98.96	98.42	98.42	99.32	98.78	98.78	98.78	98.6	97.88	97.88	98.96	98.24	98.6	98.24
60	99.0	98.5	98.6	98.78	98.42	98.42	97.16	98.78	98.6	98.6	98.6	97.88	97.88	98.96	98.06	98.6	98.24
70	99.0	98.5	98.6	98.78	98.42	98.42	99.86	98.78	98.6	98.42	98.6	97.88	97.88	98.96	98.06	98.6	98.24
80	99.0	98.5	98.6	98.6	98.42	98.42	99.95	98.6	98.6	98.42	98.24	97.88	97.88	99.14	98.06	98.6	98.24
90	99.1	98.4	98.6	98.6	98.42	98.24	100.04	98.6	98.6	98.42	98.24	97.88	97.88	99.14	98.06	98.6	98.24
100	99.1	98.4	98.78	98.6	98.42	98.24	99.68	98.6	98.6	98.42	98.24	97.88	97.88	98.96	98.06	98.6	98.24
110	99.1	98.4	98.78	98.6	98.42	98.24	99.68	98.6	98.42	98.42	98.24	97.88	97.88	98.96	98.06	98.6	98.24
120	99.2	98.3	98.78	98.6	98.42	98.24	99.32	98.6	98.24	98.42	98.06	97.88	98.06	98.96	98.24	98.6	98.24
130	99.2	98.3	98.96	98.6	98.42	98.24	98.96	98.42	98.24	98.24	98.06	97.88	97.52	98.78	98.24	98.6	98.24
140	99.2	98.3	98.96	98.6	98.42	98.42	99.34	98.6	98.24	98.24	98.06	97.88	97.34	98.78	98.42	98.42	99.86
150	99.2	98.3	99.14	98.6	98.6	98.42	99.29	98.6	98.42	98.24	97.88	97.88	97.52	98.96	98.42	98.42	97.88
160	99.3	98.3	99.14	98.6	98.6	98.42	99.24	98.6	98.42	98.42	98.06	97.88	97.7	98.96	98.42	98.42	99.86
170	99.3	98.3	99.14	98.6	98.6	98.42	99.14	98.6	98.42	98.6	98.06	97.88	97.88	98.78	98.42	98.6	98.24
180	99.4	98.3	98.96	98.6	98.6	98.42	99.14	98.6	98.42	98.78	98.06	97.88	97.88	98.96	98.42	98.6	98.24
190	99.4	98.2	99.14	98.6	98.6	98.42	99.32	98.6	98.42	99.32	98.24	97.88	98.06	98.78	98.42	98.6	98.42
200	99.3	98.3	99.14	98.6	98.6	98.42	99.32	98.6	98.42	98.78	98.24	97.88	98.06	98.78	98.42	98.6	98.42
210	99.2	98.2	99.14	98.6	98.6	98.42	99.14	98.6	98.6	98.78	98.24	98.06	98.06	98.78	98.42	98.78	98.42
220	99.3	98.3	99.14	98.6	98.6	98.42	99.32	98.6	98.6	98.96	98.24	98.24	98.06	98.78	98.42	98.78	98.24
230	99.3	98.3	99.14	98.78	98.6	98.42	99.32	98.78	98.6	98.96	98.24	98.24	98.06	98.78	98.42	98.78	98.24
240	99.2	98.3	99.14	98.78	98.78	98.42	99.32	98.78	98.78	98.96	98.42	98.24	98.06	98.96	98.24	98.78	98.24
250	99.2	98.3	98.96	98.78	98.78	98.42	99.32	98.78	98.78	98.96	98.24	98.24	98.24	99.14	98.42	98.78	98.24
260			98.96	98.78	98.78	98.42	99.32	98.78	98.6							98.78	98.24
270					98.78		99.14										
							99.32										
AVG	99.20092	98.44	98.94	98.77	98.61	98.51	98.98	98.75	98.60	98.68	98.34	97.98	98.03	99.01	98.33	98.64	98.40
SD	0.14	0.22	0.22	0.25	0.19	0.30	1.27	0.26	0.23	0.29	0.30	0.18	0.51	0.23	0.21	0.12	0.44
SE	0.03	0.04	0.04	0.05	0.04	0.06	0.24	0.05	0.04	0.06	0.06	0.03	0.10	0.04	0.04	0.02	0.08

	ABDU, 100°F																
TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
0	100.0	98.9	99.068	99.5	98.78	99.32	97.88	99.68	99.5	98.6	98.96	98.24	99.14	99.14	98.78	98.42	98.78
10	99.8	99.0	99.068	99.5	98.78	99.14	98.06	99.68	99.5	98.6	98.78	98.06	99.14	98.96	98.78	98.42	98.78
20	99.5	99.0	98.96	99.5	98.78	98.96	98.24	99.5	99.6	98.6	98.96	98.06	99.14	99.14	98.78	98.42	98.6
30	99.4	99.0	98.96	99.5	98.6	98.96	98.42	99.5	99.5	98.6	98.96	98.06	99.14	98.96	98.78	98.6	98.6
40	99.4	99.0	98.96	99.32	98.6	98.96	85.46	99.5	99.5	98.78	98.96	98.24	99.32	98.96	98.78	98.6	98.78
50	99.3	99.0	98.96	99.32	98.6	98.96	89.96	99.32	99.5	98.78	98.96	98.24	99.32	98.96	98.78	98.78	98.78
60	99.3	99.0	98.96	99.32	98.6	98.96	94.28	99.32	99.5	98.78	98.96	98.24	99.32	98.96	98.78	98.78	98.78
70	99.3	99.1	99.14	99.5	98.6	98.96	97.34	99.32	99.5	98.96	98.96	98.24	99.32	99.14	98.96	98.78	98.96
80	99.4	99.1	99.14	99.5	98.78	98.96	93.74	99.32	99.5	98.96	98.96	98.42	99.32	99.32	98.96	98.78	98.96
90	99.5	99.2	99.14	99.5	98.78	99.14	96.8	99.32	99.5	98.96	98.96	98.42	99.32	99.32	99.14	98.78	98.96
100	99.5	99.2	99.32	99.5	98.6	99.14	98.06	99.32	99.68	98.96	98.96	98.6	99.32	99.32	99.14	98.78	99.14
110	99.6	99.2	99.32	99.5	98.78	99.14	102.2	99.32	99.68	98.96	98.96	98.6	99.5	99.5	99.32	98.96	99.14
120	99.6	99.2	99.32	99.5	98.6	99.14	96.44	99.5	99.86	99.14	99.14	98.6	99.5	99.5	99.32	98.96	99.14
130	99.7	99.1	99.5	99.5	98.78	99.14	97.7	99.5	100.04	98.96	98.96	98.78	99.32	99.68	99.32	98.6	99.14
140	99.8	99.4	99.5	99.5	98.78	99.32	98.42	99.68	100.04	98.96	99.14	98.78	99.32	99.68	99.32	98.78	99.14
150	99.9	99.5	99.5	99.5	98.78	99.32	99.14	99.68	100.04	98.96	99.32	98.78	99.86	99.32	99.32	98.78	99.14
160	99.8	99.7	99.68	99.5	98.96	99.5	99.5	99.68	100.22	99.14	99.32	98.96	99.32	99.32	99.32	98.78	99.14
170	99.8	99.4	99.68	99.68	98.78	99.5	99.5	99.86	100.22	99.14	99.5	98.96	99.32	99.32	99.32	98.96	99.32
180	99.9	99.5	99.68	99.68	98.96	99.68	101.48	99.86	100.4	99.14	99.5	98.96	99.6	99.32	99.32	98.96	99.32
190	100.0	99.5	99.68	99.68	98.96	99.5	99.32	100.04	100.58	99.32	99.32	99.14	99.32	99.32	99.32	98.96	99.32
200	100.0	99.5	99.86	99.68	98.96	99.68	99.5	100.04	100.58	99.32	99.5	99.14	99.32	99.32	99.32	98.96	99.5
210	100.1	99.6	99.86	99.68	99.14	99.68	100.4	100.22	100.76	99.32	99.5	99.32	99.5	99.32	99.32	98.96	99.5
220	100.2	99.6	99.68	99.68	99.14	99.68	99.68	100.4	100.76	99.32	99.5	99.32	99.32	99.32	99.32	98.96	99.68
230	100.3	99.6	99.68	99.68	99.14	99.68	99.68	100.58	100.76	99.32	99.5	99.14	99.32	99.32	99.32	98.96	99.86
240	100.3	99.5	99.86	99.86	99.14	100.04	99.68	100.58	100.94	99.5	99.68	99.32	99.5	99.32	99.32	98.96	99.68
250	100.3	99.5	99.86	99.86	99.14	99.86	99.86	100.76	101.12		99.5	99.5	99.5	99.5	99.32	98.78	99.86
260	100.3	99.6			99.14	99.86	99.32							99.68	99.5		
270					99.14	99.86	99.5										
					99.14		99.68										
AVG	99.79	99.29	99.40	99.56	98.86	99.36	97.90	99.75	100.03	99.00	99.18	98.70	99.35	99.29	99.15	98.79	99.15
SD	0.34	0.25	0.34	0.14	0.21	0.34	3.39	0.44	0.55	0.26	0.27	0.45	0.15	0.22	0.25	0.18	0.38
SE	0.06	0.05	0.06	0.03	0.04	0.07	0.64	0.08	0.10	0.05	0.05	0.09	0.03	0.04	0.05	0.03	0.07

Table A-6. (continued)

Test subject core temperature data.

TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
	MOPP4, 70°F																
0	99.6	99.6	99.86	99.68	99.32	100.04	99.014	99.86	100.04	99.68	99.32	98.96	98.42	99.86	100.04	99.32	98.96
10	99.4	99.1	99.68	99.68	99.14	100.04	99.194	99.68	100.04	99.5	99.14	98.78	98.42	99.86	99.5	99.14	98.78
20	99.3	99.0	99.5	99.5	99.14	99.68	99.538	99.5	100.04	99.32	99.14	98.6	98.42	99.86	99.32	99.14	98.6
30	99.2	98.9	99.5	99.32	98.96	99.68	99.914	99.32	100.04	99.32	98.96	98.42	98.24	99.5	99.32	99.14	98.42
40	99.0	98.8	99.5	99.32	98.96	99.5	100.58	99.23	99.86	99.32	98.96	98.42	98.24	99.5	99.32	99.14	100.22
50	98.9	98.7	99.5	99.32	98.78	99.32	100.76	99.14	99.86	99.14	98.96	98.06	98.06	99.32	99.14	98.96	98.24
60	98.9	98.6	99.5	99.32	98.6	99.32	100.76	99.14	99.68	99.14	98.78	98.06	98.06	99.14	99.14	99.05	98.06
70	99.0	98.5	99.5	99.32	98.6	99.32	100.4	98.96	99.86	98.96	98.78	98.06	98.06	98.96	98.96	97.88	97.88
80	99.0	98.5	99.5	99.32	98.6	99.14	100.22	98.96	99.5	98.78	98.6	98.06	98.06	98.96	98.96	98.96	97.88
90	99.0	98.5	99.32	99.14	98.42	99.14	100.04	98.78	99.5	98.78	98.6	98.06	97.88	98.78	98.78	98.78	97.88
100	99.1	98.4	99.32	99.14	98.42	99.14	99.68	98.78	99.32	98.78	98.42	97.88	97.88	98.6	98.6	98.78	97.88
110	99.1	98.5	99.32	99.14	98.42	99.14	99.68	98.6	99.32	98.6	98.42	97.88	97.88	98.6	98.6	98.78	97.88
120	99.1	98.5	99.14	98.96	98.42	99.14	99.86	98.6	99.32	98.42	98.42	97.88	97.7	98.6	98.6	98.78	97.7
130	99.1	98.5	99.14	98.96	98.24	99.14	99.86	98.6	99.32	98.06	98.42	97.88	97.7	98.24	98.24	98.42	97.88
140	99.2	98.5	99.14	98.96	98.24	99.14	99.68	98.6	99.32	98.42	98.42	97.88	97.7	98.24	98.24	98.42	98.06
150	99.2	98.5	99.32	98.96	98.24	99.14	99.68	98.6	99.32	98.24	98.06	97.88	97.52	98.24	98.42	98.6	98.06
160	99.2	98.5	99.32	98.96	98.24	99.14	99.68	98.6	99.14	98.06	98.06	98.06	97.7	98.24	98.42	98.6	98.06
170	99.3	98.5	99.32	98.96	98.24	99.14	99.68	98.6	99.14	98.06	98.24	97.88	97.7	98.24	98.6	98.6	98.06
180	99.4	98.5	99.32	98.78	98.24	99.14	99.68	98.6	99.14	98.06	98.24	98.06	97.7	98.24	98.6	98.6	97.88
190	99.4	98.4	99.32	98.78	98.24	99.14	99.68	98.78	99.14	98.06	98.24	98.06	97.7	98.24	98.6	98.6	98.06
200	99.4	98.4	99.32	98.78	98.24	99.14	99.5	98.6	99.14	98.06	100.04	97.88	97.7	98.24	98.6	98.6	98.24
210	99.3	98.4	99.32	98.78	98.24	99.14	99.68	98.78	99.14	98.06	98.06	98.06	97.7	98.24	98.6	98.42	98.24
220	99.3	98.4	99.32	98.78	98.42	98.96	99.5	98.78	99.32	98.24	98.24	98.06	97.7	98.24	98.6	98.42	98.24
230	99.3	98.4	99.32	98.78	98.24	99.14	99.5	98.78	99.32	98.24	98.24	98.06	97.7	98.42	98.42	98.42	98.24
240	99.4	98.4	99.32	98.6	98.42	98.96	98.96	98.78	99.32	98.24	98.24	98.06	97.88	98.42	98.6	98.42	98.24
250	99.4	98.4	99.5	98.78	98.42	98.96	99.32	98.78	99.32	98.24	98.24	98.06	97.7	98.42	98.42	98.42	98.24
260	99.3	98.5	99.32	98.78		98.96	99.14			98.24	98.24	98.06	97.7			98.42	
270		98.5	99.32	98.6			99.14			98.24	98.24						
			99.32	98.6			99.14			98.24	98.24						
AVG	99.21	98.55	99.37	99.03	98.52	99.25	99.71	98.90	99.48	98.57	98.55	98.11	97.89	98.74	98.79	98.70	98.23
SD	0.16	0.19	0.13	0.31	0.33	0.29	0.48	0.36	0.33	0.52	0.48	0.28	0.28	0.58	0.43	0.33	0.50
SE	0.03	0.04	0.02	0.06	0.06	0.06	0.09	0.07	0.06	0.10	0.09	0.05	0.05	0.11	0.08	0.06	0.09

TIME(MIN)	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10	TS11	TS12	TS13	TS14	TS15	TS16	TS17
	MOPP4, 100°F																
0	101.1	100.5	100.76	100.94	100.04	100.22	98.566	100.76	100.04	100.76	100.04	99.86	99.86	100.58	100.22	99.86	100.04
10	101.2	100.7	100.94	100.58	100.04	100.4	96.8	100.94	100.22	101.12	100.58	100.04	100.04	100.58	100.76	100.04	100.22
20	101.3	101.0	101.48	100.76	100.22	100.76	98.852	101.3	100.58	101.48		100.04	100.22	100.94	101.12	100.4	100.4
30	101.4	101.4	101.66	100.94	100.4	100.94	94.78	101.48	100.94	102.02		100.22	100.4	101.12	101.66	100.58	100.58
40	101.6	101.7	102.02	101.3	100.58	101.12	91.76	101.84	101.3	102.38		100.58	100.58	101.3	101.84	100.76	100.94
50	101.9	102.3	102.2	101.48	100.94	100.4	92.12	102.2	101.48	102.56		100.94	100.94	101.48	102.2	101.12	101.12
60	102.2	102.0	102.38		101.12		95.72	102.56				101.12	101.12	101.84	102.47	101.48	101.3
70			102.58		101.48		97.52						101.48	101.966	102.614	101.66	101.48
80					101.84		97.88						101.66			101.84	101.66
90					102.02		98.6						101.84			102.02	101.84
100					102.38		100.94						102.164			102.2	102.2
110					102.56								102.326			102.56	102.38
120																	102.56
130																	
140																	
150																	
160																	
170																	
180																	
190																	
200																	
210																	
220																	
230																	
240																	
250																	
260																	
270																	
AVG	101.59	101.36	101.75	101.00	101.14	100.64	96.50	101.58	100.76	101.72	100.31	100.40	101.05	101.23	101.61	101.21	101.29
SD	0.38	0.66	0.66	0.34	0.91	0.35	2.79	0.66	0.58	0.72	0.38	0.49	0.84	0.52	0.85	0.88	0.83
SE	0.07	0.13	0.12	0.06	0.17	0.07	0.53	0.12	0.11	0.14	0.07	0.09	0.16	0.10	0.16	0.17	0.16

Appendix B. MANOVA and ANOVA Results Tables

Table B-1.

General MANOVA for physiological data.

Heart Rate

Summary of All Effects

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Temperature	0.00759	313.6536	5	12	0.0000
Uniform	0.02389	98.0428	5	12	0.0000
Temperature and Uniform	0.01034	229.6922	5	12	0.0000

Core Temperature

Summary of All Effects

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Temperature	0.00001	301268.0938	5	11	0.0000
Uniform	0.00003	75876.6953	5	11	0.0000
Temperature and Uniform	0.00001	271656.4375	5	11	0.0000

Sweat and Fluid Balance

Summary of All Effects

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Temperature	0.05073	21.8314	6	7	0.0003
Uniform	0.03756	29.8970	6	7	0.0001
Temperature and Uniform	0.10345	10.1107	6	7	0.0037

Table B-2.

Repeated measures ANOVA results for core temperature and heart rate.

MEAN CORE TEMPERATURE AND TIME TO MAX CORE TEMPERATURE BY CONDITION						MAIN EFFECTS TEMPERATURE		MAIN EFFECTS UNIFORM		INTERACTION TEMPERATURE X UNIFORM	
EVENT	NUM TSs	ABDU, 70°F	MOPP4, 70°F	ABDU, 100°F	MOPP4, 100°F	F VALUE(1,15)	P VALUE	F VALUE(1,15)	P VALUE	F VALUE(1,15)	P VALUE
PRE-FLIGHT											
AVERAGE	17	98.46	98.87	98.51	98.89	0.66	0.4308	28.25	0.0001	0.06	0.8030
MAX	17	98.85	99.25	98.80	99.42	0.60	0.4518	44.31	0.0000	1.44	0.2488
TIME TO MAX	17	0:18	0:17	0:18	0:19	0.59	0.4552	0.08	0.7807	2.20	0.1591
SIMULATOR											
AVERAGE	17	98.63	98.73	99.29	101.09	321.12	0.0000	178.74	0.0000	99.10	0.0000
MAX	17	99.68	99.56	99.84	102.01	31.07	0.0001	12.59	0.0029	33.05	0.0000
TIME TO MAX	17	1:05	0:45	2:40	0:54	3.90	0.0669	9.55	0.0075	2.21	0.1581
CUMULATIVE											
AVERAGE	17	98.58	98.72	99.17	100.49	238.30	0.0000	112.17	0.0000	52.19	0.0000
MAX	17	99.67	99.62	99.84	102.00	32.27	0.0000	12.83	0.0027	30.79	0.0001
MIN	17	97.82	98.13	98.07	98.22	3.90	0.0671	3.53	0.0799	0.51	0.4868

MEAN HEART RATES AND TIMES TO MAX HEART RATE BY CONDITION						MAIN EFFECTS TEMPERATURE		MAIN EFFECTS UNIFORM		INTERACTION TEMPERATURE X UNIFORM	
EVENT	NUM TSs	ABDU, 70°F	MOPP4, 70°F	ABDU, 100°F	MOPP4, 100°F	F VALUE(1,16)	P VALUE	F VALUE(1,16)	P VALUE	F VALUE(1,16)	P VALUE
PRE-FLIGHT											
AVERAGE	17	95.94	114.41	99.37	127.25	23.56	0.0002	44.59	0.0000	3.18	0.0935
MAX	17	106.88	126.59	109.29	141.71	11.97	0.0032	49.70	0.0000	3.43	0.0825
TIME TO MAX	17	0:15	0:16	0:16	0:16	1.00	0.3323	1.00	0.3315	1.00	0.3316
SIMULATOR											
AVERAGE	17	75.48	84.57	92.75	132.55	302.66	0.0000	106.74	0.0000	82.91	0.0000
MAX	17	87.61	109.60	110.84	144.51	163.95	0.0000	70.20	0.0000	4.50	0.0499
TIME TO MAX	17	1:49	0:50	3:15	0:24	0.98	0.3376	1.05	0.3213	0.97	0.3408
CUMULATIVE											
AVERAGE	17	76.71	86.48	93.09	130.70	257.25	0.0000	110.03	0.0000	83.56	0.0000
MAX	17	106.89	121.62	115.13	149.99	65.64	0.0000	66.18	0.0000	7.07	0.0172
MIN	17	64.67	70.60	75.28	86.65	32.51	0.0000	12.85	0.0025	2.35	0.1446

Table B-3.

Repeated measures ANOVA results for sweat and fluid balance.

MEAN FOR SWEAT AND FLUID BALANCE BY CONDITION						MAIN EFFECTS				INTERACTION	
						TEMPERATURE		UNIFORM		TEMPERATURE X UNIFORM	
EVENT	NUM TSs	ABDU, 70°F	MOPP4, 70°F	ABDU, 100°F	MOPP4, 100°F	F VALUE(1,12)	P VALUE	F VALUE(1,12)	P VALUE	F VALUE(1,12)	P VALUE
CUMULATIVE (gms/hr)											
SWEAT TOTAL	13	103.85	435.10	207.04	1494.29	108.00	0.0000	77.67	0.0000	51.23	0.0000
SWEAT EVAPORATED	13	92.08	279.17	111.81	392.83	37.92	0.0000	5.32	0.0398	4.13	0.0648
SWEAT RETAINED	13	17.18	155.93	95.22	1101.46	63.81	0.0000	66.87	0.0000	59.22	0.0000
WATER INTAKE	13	181.43	406.19	163.48	546.80	42.62	0.0000	2.03	0.1797	5.88	0.0321
URINE OUTPUT	13	111.47	80.20	94.80	175.44	0.79	0.3915	2.51	0.1388	9.60	0.0092
% DEHYDRATION	13	0.22	0.70	0.88	2.45	40.72	0.0000	46.89	0.0000	14.76	0.0023

Table B-4.
General MANOVA for questionaire data.

Mood and symptoms
Summary of All Effects

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Temperature	0.00418	99.2664	12	5	0.0000
Uniform	0.00312	133.0323	12	5	0.0000
Temperature and Uniform	0.01320	31.1580	12	5	0.0007

TLX
Summary of All Effects

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Temperature	0.19484	6.8872	6	10	0.0041
Uniform	0.27913	4.3042	6	10	0.0210
Temperature and Uniform	0.27689	4.3526	6	10	0.0203

POMS
Summary of All Effects

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Temperature	0.02879	48.1987	7	10	0.0000
Uniform	0.04329	31.5677	7	10	0.0000
Temperature and Uniform	0.06209	21.5806	7	10	0.0000

Table B-5.

Repeated measures ANOVA results for mood and symptoms, POMS, and TLX.

MEANS FOR MOOD and SYMPTOMS QUESTIONAIRE BY CONDITION						MAIN EFFECTS TEMPERATURE		UNIFORM		INTERACTION TEMPERATURE X UNIFORM	
QUESTION	NUM TSs	ABDU, 70°F	MOPP4, 70°F	ABDU, 100°F	MOPP4, 100°F	F VALUE(1,16)	P VALUE	F VALUE(1,16)	P VALUE	F VALUE(1,16)	P VALUE
HEADACHE	17	0.07	0.83	0.08	0.81	0.00	0.9803	24.43	**0.0001**	0.02	0.8893
NAUSEA	17	0.10	0.21	0.12	0.52	6.85	**0.0187**	7.69	**0.0136**	4.27	0.0554
STRESS	17	0.86	1.78	1.25	2.56	21.46	**0.0003**	16.67	**0.0009**	1.87	0.1903
ANGER	17	0.13	0.78	0.19	0.80	0.60	0.4503	6.50	**0.0214**	0.16	0.6946
DEPRESSION	17	0.07	0.25	0.19	0.48	3.74	0.0711	3.95	0.0644	0.63	0.4381
ENERGY	17	7.15	6.32	6.14	6.28	12.10	**0.0031**	2.82	0.1127	6.99	**0.0177**
HEAT STRESS	17	0.35	1.35	2.53	3.46	116.69	**0.0000**	15.67	**0.0011**	0.03	0.8686
THIRST	17	0.54	1.00	1.12	1.37	25.38	**0.0001**	8.18	**0.0113**	0.73	0.4060
WORKLOAD	17	1.86	2.34	1.89	3.33	16.76	**0.0008**	14.07	**0.0017**	8.64	**0.0096**
BOREDOM	17	1.74	1.68	1.89	1.29	1.64	0.2190	5.21	**0.0365**	2.98	0.1034
DIZZENESS	17	0.00	0.03	0.04	0.38	6.92	**0.0182**	6.01	**0.0261**	5.54	**0.0316**
VISUAL DIFFICULTY	17	0.47	2.76	0.64	2.36	0.62	0.4414	15.42	**0.0012**	1.88	0.1894

MEANS FOR POMS QUESTIONAIRE BY CONDITION						TEMPERATURE		UNIFORM		TEMPERATURE X UNIFORM	
QUESTION	NUM TSs	ABDU, 70°F	MOPP4, 70°F	ABDU, 100°F	MOPP4, 100°F	F VALUE(1,16)	P VALUE	F VALUE(1,16)	P VALUE	F VALUE(1,16)	P VALUE
VIGOR	17	19.38	16.44	16.91	16.00	6.93	**0.0181**	13.35	**0.0021**	3.87	0.0669
ANGER-HOSTILITY	17	2.24	3.76	2.38	4.09	0.25	0.6237	7.05	**0.0173**	0.03	0.8650
FATIGUE	17	2.82	5.06	4.91	7.38	21.91	**0.0003**	40.97	**0.0000**	0.06	0.8083
TENSION-ANXIETY	17	-1.0000	0.5882	-0.4412	1.5588	5.25	**0.0359**	9.83	**0.0064**	0.28	0.6066
CONFUSION-BEWILDERMENT	17	-1.38	-0.29	-0.65	0.56	16.69	**0.0009**	10.19	**0.0057**	0.07	0.7983
DEPRESSION-DEJECTION	17	1.88	3.03	1.97	4.06	1.40	0.2536	10.04	**0.0060**	0.63	0.4372
TOTAL MOOD DISTURBANCE	17	-14.82	-4.29	-8.74	1.65	17.14	**0.0008**	19.48	**0.0004**	0.00	0.9698

MEANS OF TLX QUESTIONNAIRE BY CONDITION						MAIN EFFECTS TEMPERATURE		UNIFORM		INTERACTION TEMPERATURE X UNIFORM	
QUESTION	NUM TSs	ABDU, 70°F	MOPP4, 70°F	ABDU, 100°F	MOPP4, 100°F	F VALUE(1,15)	P VALUE	F VALUE(1,15)	P VALUE	F VALUE(1,15)	P VALUE
MENTAL DEMAND	17	8.78	9.68	9.63	10.93	5.01	**0.0408**	7.96	**0.0129**	0.32	0.5779
PHYSICAL DEMAND	17	5.23	8.16	5.78	8.75	21.05	**0.0004**	12.16	**0.0033**	8.24	**0.0117**
TEMPORAL DEMAND	17	7.19	7.96	7.31	8.97	3.90	0.0670	9.48	**0.0076**	1.34	0.2658
PERFORMANCE	17	12.45	6.12	1.44	4.00	0.44	0.5172	4.17	0.0592	0.28	0.6022
EFFORT	17	10.16	11.46	10.83	12.69	6.00	**0.0270**	15.77	**0.0012**	0.84	0.3752
FRUSTRATION	17	3.59	4.85	3.25	5.57	0.09	0.7710	6.42	**0.0230**	0.70	0.4144

Appendix C. Correlation Tables

Table C-1.

Correlations of physiological data.

Shaded Correlations Are Significant At p≤ .05

	AGE	HEIGHT	WEIGHT	PT SCORE	HEAT STRESS TRAINING	TOTAL FLIGHT TIME	UH60 FLIGHT TIME	TOTAL SIMULATED FLIGHT	UNIFORM	TEMPERATURE	MAX CORE TEMP	SWEAT LOSS PER HOUR	% DEHYDRATION	MEAN SKIN TEMP	ARM TEMP	CHEST TEMP	THIGH TEMP	LEG TEMP	MAX HEART RATE
AGE	1.0000																		
HEIGHT	-0.1861	1.0000																	
WEIGHT	0.1957	0.6444	1.0000																
PT SCORE	-0.0680	-0.3804	-0.4576	1.0000															
HEAT STRESS TRAINING	-0.5084	0.2907	-0.0962	-0.2090	1.0000														
TOTAL FIGHT TIME	0.2644	0.1484	0.1164	-0.2585	0.5307	1.0000													
UH60 FLIGHT TIME	-0.1086	-0.3205	-0.0641	0.1554	-0.2323	0.0455	1.0000												
TOT SIMULATED FLIGHT	-0.1335	-0.3137	-0.1366	0.1905	-0.0827	0.0023	0.8709	1.0000											
UNIFORM	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000										
TEMPERATURE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000									
MAX CORE TEMP	-0.0886	-0.0082	-0.1056	0.0240	-0.0699	-0.1397	0.0636	0.0461	0.6219	0.5369	1.0000								
SWEAT LOSS PER HOUR	0.0265	0.0423	0.0937	0.0878	0.0622	0.1117	0.0573	0.0550	0.6612	0.4713	0.7511	1.0000							
% DEHYDRATION	0.2078	0.0039	0.1863	0.1640	-0.0662	0.0706	0.1215	0.1425	0.4300	0.4101	0.5340	0.6886	1.0000						
SKIN TEMPERATURE	-0.0352	-0.0753	-0.0559	-0.0360	-0.0613	-0.0769	0.0289	0.0031	0.8095	0.5021	0.8300	0.7350	0.5020	1.0000					
ARM TEMPERATURE	0.0969	-0.0533	0.0406	-0.0689	-0.0907	-0.0561	-0.0315	-0.0548	0.6124	0.4519	0.6248	0.6112	0.4059	0.8379	1.0000				
CHEST TEMPERATURE	-0.1673	-0.1509	-0.2342	0.0599	-0.0679	-0.1332	0.1563	0.1409	0.5904	0.4863	0.8242	0.5922	0.3728	0.8314	0.5055	1.0000			
THIGH TEMPERATURE	-0.0705	-0.0228	-0.0088	0.0103	0.0010	-0.0044	0.0171	-0.0093	0.7894	0.5187	0.7677	0.7052	0.5216	0.9525	0.7231	0.7697	1.0000		
LEG TEMPERATURE	-0.0141	-0.0568	-0.0358	-0.1244	-0.0632	-0.0987	-0.0170	-0.0424	0.8861	0.3098	0.7545	0.6960	0.4717	0.9231	0.6744	0.7390	0.8819	1.0000	
MAX HEART RATE	-0.2255	-0.1005	-0.0278	-0.0881	0.1645	-0.0416	-0.0627	-0.0488	0.4207	0.5749	0.6637	0.6225	0.3518	0.6762	0.5470	0.6030	0.6572	0.5941	1.0000

Table C-2.

Correlations of questionnaire data: Profile of mood states vs. ACS scores.

Shaded Correlations Are Significant At p≤ .05

	TEMPERATURE	ACS HOVER	ACS HOVER TURN	ACS RSRT	ACS LCT	ACS SL	ACS LDT	ACS NOE	ACS CONTOUR	PRE VIGOR	PRE ANGER-HOSTILITY	PRE FATIGUE
TEMPERATURE	1.0000											
ACS HOVER	-0.1689	1.0000										
ACS HOVER TURN	0.0555	0.0522	1.0000									
ACS RSRT	-0.2079	0.1957	0.2796	1.0000								
ACS LCT	0.0255	-0.0586	0.3666	0.2056	1.0000							
ACS SL	-0.0645	0.0042	0.1905	0.5970	0.5870	1.0000						
ACS LDT	-0.0610	-0.2336	0.3391	0.0025	0.2973	0.1894	1.0000					
ACS NOE	0.0104	-0.0918	0.0939	0.2622	0.3896	0.4060	-0.1383	1.0000				
ACS CONTOUR	-0.0101	0.0136	0.2259	0.1991	0.3623	0.4705	0.0252	0.5615	1.0000			
PRE VIGOR	-0.0385	-0.0802	0.1416	0.2479	0.0931	0.0935	-0.0299	-0.1740	-0.2146	1.0000		
PRE ANGER-HOSTILITY	0.0759	-0.0978	-0.1240	-0.1820	-0.1330	-0.0884	-0.3000	-0.1003	-0.2378	-0.1935	1.0000	
PRE FATIGUE	0.0260	0.1108	-0.1706	-0.1318	-0.2162	-0.1870	-0.4090	-0.0364	-0.0766	-0.2448	0.7380	1.0000
PRE TENSION-ANXIETY	0.0030	-0.0187	-0.2742	-0.3801	-0.2251	-0.2543	-0.1446	-0.2211	-0.1989	-0.5245	0.6668	0.4778
PRE CONFUSION-BEWILDERMEN	0.0183	-0.1116	-0.1540	-0.2510	-0.2291	-0.1907	-0.2057	-0.1402	-0.1175	-0.4056	0.8889	0.7922
PRE DEPRESSION-DEJECTION	0.0357	-0.0877	-0.1437	-0.2487	-0.1500	-0.1851	-0.2617	-0.2117	-0.2005	-0.1715	0.9166	0.7709
PRE TOTAL MOOD DISTURBANC	0.0428	-0.0196	-0.2071	-0.2994	-0.2080	-0.1990	-0.2499	-0.0930	-0.1106	-0.5628	0.8755	0.7943
POST VIGOR	-0.3249	-0.3179	0.1805	0.3103	0.1803	0.2698	-0.0482	0.1487	0.0178	0.6173	0.0610	-0.1192
POST ANGER-HOSTILITY	0.1094	-0.0194	-0.0858	-0.1479	-0.0062	-0.0428	-0.3316	-0.0409	-0.2166	-0.2280	0.9475	0.7630
POST FATIGUE	0.4182	0.1959	-0.5314	-0.3666	-0.2708	-0.4539	-0.3282	-0.2252	-0.2346	-0.1142	0.2030	0.3993
POST TENSION-ANXIETY	0.1611	0.0406	-0.2503	-0.2722	-0.0240	-0.1457	-0.0942	-0.0391	-0.0047	-0.6694	0.3063	0.3164
POST CONFUSION-BEWILDERME	0.1849	-0.0622	-0.3437	-0.3799	-0.1020	-0.3123	-0.2110	-0.1718	-0.1448	-0.3359	0.7356	0.6940
POST DEPRESSION-DEJECTION	0.0416	-0.0148	-0.1886	-0.2165	-0.0464	-0.2010	-0.3444	-0.1268	-0.0819	-0.2658	0.8468	0.8114
POST TOTAL MOOD DISTURBAN	0.3187	0.1537	-0.3691	-0.3937	-0.1699	-0.3468	-0.2660	-0.1834	-0.1588	-0.5147	0.5757	0.6428
UNIFORM	-0.0294	0.1743	-0.4902	-0.3175	-0.0557	-0.2659	-0.0038	-0.1936	-0.4550	-0.0282	0.1119	-0.0188

	PRE TENSION-ANXIETY	PRE CONFUSION-BEWILDERMENT	PRE DEPRESSION-DEJECTION	PRE TOTAL MOOD DISTURBANCE	POST VIGOR	POST ANGER-HOSTILITY	POST FATIGUE	POST TENSION-ANXIETY	OST CONFUSION-BEWILDERMEN	POST DEPRESSION-DEJECTION	POST TOTAL MOOD DISTURBANCE	UNIFORM
PRE TENSION-ANXIETY	1.0000											
PRE CONFUSION-BEWILDERMEN	0.7742	1.0000										
PRE DEPRESSION-DEJECTION	0.7293	0.9113	1.0000									
PRE TOTAL MOOD DISTURBANC	0.8540	0.9558	0.8892	1.0000								
POST VIGOR	-0.3958	-0.0996	-0.0394	-0.2779	1.0000							
POST ANGER-HOSTILITY	0.5323	0.8107	0.8520	0.8241	0.0152	1.0000						
POST FATIGUE	0.3174	0.2557	0.2935	0.3143	-0.5808	0.2217	1.0000					
POST TENSION-ANXIETY	0.6875	0.4702	0.3894	0.5962	-0.5614	0.3399	0.3768	1.0000				
POST CONFUSION-BEWILDERME	0.7478	0.7894	0.8136	0.8256	-0.3400	0.6778	0.6500	0.5517	1.0000			
POST DEPRESSION-DEJECTION	0.6371	0.8333	0.9099	0.8586	-0.1157	0.8585	0.3966	0.4694	0.8677	1.0000		
POST TOTAL MOOD DISTURBAN	0.7015	0.6520	0.6559	0.7647	-0.6792	0.6063	0.7804	0.7288	0.8744	0.7535	1.0000	
UNIFORM	0.2274	0.0520	0.0933	0.1033	-0.1942	0.1246	0.4491	0.1434	0.3209	0.1682	0.3313	1.0000

Table C-3.
Correlations of questionnaire data: Task load index vs. ACS scores.

Shaded Correlations Are Significant At p≤ .05

	TEMPERATURE	ACS HOVER	ACS HOVER TURN	ACS RSRT	ACS LCT	ACS SL	ACS LDT	ACS NOE	ACS CONTOUR	MENTAL DEMAND	PHYSICAL DEMAND	TEMPORAL DEMAND	PERFORMANCE	EFFORT	FRUSTRATION	UNIFORM
TEMPERATURE	1.0000															
ACS HOVER	-0.1689	1.0000														
ACS HOVER TURN	0.0555	0.0522	1.0000													
ACS RSRT	-0.2079	0.1957	0.2796	1.0000												
ACS LCT	0.0255	-0.0586	0.3666	0.2056	1.0000											
ACS SL	-0.0645	0.0042	0.1905	0.5970	0.5870	1.0000										
ACS LDT	-0.0610	-0.2336	0.3391	0.0025	0.2973	0.1894	1.0000									
ACS NOE	0.0104	-0.0918	0.0939	0.2622	0.3896	0.4060	-0.1383	1.0000								
ACS CONTOUR	-0.0101	0.0136	0.2259	0.1991	0.3623	0.4705	0.0252	0.5615	1.0000							
MENTAL DEMAND	0.1892	0.1697	0.0881	-0.3488	-0.0884	-0.4698	0.1078	-0.2492	-0.2031	1.0000						
PHYSICAL DEMAND	0.2676	0.1084	-0.1217	-0.4781	-0.2650	-0.4997	0.0107	-0.2658	-0.2911	0.8650	1.0000					
TEMPORAL DEMAND	0.0708	0.0934	0.2053	-0.2191	-0.0598	-0.2954	0.1138	-0.2267	-0.2851	0.7221	0.6854	1.0000				
PERFORMANCE	0.0163	0.3282	-0.0045	-0.1965	0.0133	-0.1192	-0.1614	0.0340	-0.1632	0.5618	0.3884	0.2560	1.0000			
EFFORT	0.0942	0.2778	0.0432	-0.3202	-0.1299	-0.3736	0.0413	-0.2069	-0.1660	0.9132	0.8446	0.8180	0.5567	1.0000		
FRUSTRATION	0.1400	-0.1382	-0.3648	-0.3497	-0.1689	-0.1326	-0.2488	0.1506	-0.2653	0.1303	0.4114	0.1294	0.1923	0.2054	1.0000	
UNIFORM	-0.0294	0.1743	-0.4902	-0.3175	-0.0557	-0.2659	-0.0038	-0.1936	-0.4550	0.1122	0.2452	0.0819	0.0995	0.1138	0.2098	1.0000

Table C-4.

Correlations of questionnaire data: Mood symptoms vs. ACS scores.

Shaded Correlations Are Significant At p≤ .05

	TEMPERATURE	ACS HOVER	ACS HOVER TURN	ACS RSRT	ACS LCT	ACS SL	ACS LDT	ACS NOE	ACS CONTOUR	HEADACHE	NAUSEA
TEMPERATURE	1.0000										
ACS HOVER	-0.1689	1.0000									
ACS HOVER TURN	0.0555	0.0522	1.0000								
ACS RSRT	-0.2079	0.1957	0.2796	1.0000							
ACS LCT	0.0255	-0.0586	0.3686	0.2056	1.0000						
ACS SL	-0.0645	0.0042	0.1905	0.5970	0.5870	1.0000					
ACS LDT	-0.0610	-0.2336	0.3391	0.0025	0.2973	0.1894	1.0000				
ACS NOE	0.0104	-0.0918	0.0939	0.2622	0.3896	0.4060	-0.1383	1.0000			
ACS CONTOUR	-0.0101	0.0136	0.2259	0.1991	0.3623	0.4705	0.0252	0.5615	1.0000		
HEADACHE	-0.0852	0.0119	-0.5308	-0.4249	-0.0335	-0.1400	-0.1139	-0.0576	-0.2962	1.0000	
NAUSEA	0.1253	-0.0878	-0.2942	-0.2938	-0.2028	-0.2180	-0.3790	-0.1183	-0.2604	0.4333	1.0000
STRESS	0.1009	-0.0642	-0.4589	-0.4750	-0.2737	-0.3115	-0.2251	-0.1575	-0.2153	0.6491	0.7257
ANGER	-0.0598	0.0039	-0.2870	-0.1926	-0.1422	-0.0388	-0.1586	-0.1229	-0.2116	0.4225	0.7640
DEPRESS	0.0362	-0.0753	-0.1683	-0.2123	-0.2541	-0.1121	-0.1617	-0.2588	-0.2473	0.2949	0.7462
ENERGY	-0.2012	-0.0174	0.4233	0.4327	0.3668	0.3222	0.2369	-0.0002	-0.0236	-0.4650	-0.4661
HEAT STRESS	0.6515	-0.0914	-0.3080	-0.3688	-0.2086	-0.2356	-0.1993	-0.1430	-0.1663	0.4507	0.5918
THIRST	0.1646	0.0657	-0.3089	-0.3155	-0.2577	-0.2891	-0.0316	-0.2267	-0.1311	0.5439	0.4205
WORKLOAD	0.1247	0.0908	-0.1518	-0.3383	-0.2458	-0.4340	-0.0652	-0.4309	-0.5074	0.3392	0.5038
BOREDOM	-0.0417	-0.1277	0.1054	0.0606	0.0589	0.3738	0.0423	0.2420	0.3094	0.0587	0.2361
DIZZINES	0.2612	-0.0587	-0.3081	-0.3798	-0.1427	-0.2908	-0.3774	-0.0240	-0.2221	0.5660	0.7437
VISUAL DIFFICULTY	-0.0478	0.0343	-0.5288	-0.4014	-0.2084	-0.2686	-0.2712	-0.2274	-0.3039	0.6917	0.7997
UNIFORM	-0.0294	0.1743	-0.4902	-0.3175	-0.0557	-0.2659	-0.0038	-0.1936	-0.4550	0.5603	0.2171

	STRESS	ANGER	DEPRESS	ENERGY	HEAT STRESS	THIRST	WORKLOAD	BOREDOM	DIZZINES	VISUAL DIFFICULTY	UNIFORM
STRESS	1.0000										
ANGER	0.6552	1.0000									
DEPRESS	0.6780	0.8607	1.0000								
ENERGY	-0.6483	-0.2845	-0.2631	1.0000							
HEAT STRESS	0.7565	0.4426	0.5212	-0.5352	1.0000						
THIRST	0.7672	0.3268	0.3814	-0.6140	0.6807	1.0000					
WORKLOAD	0.5904	0.4316	0.4651	-0.2387	0.5226	0.5014	1.0000				
BOREDOM	0.1400	0.2654	0.2585	-0.2145	0.0981	-0.1125	-0.2347	1.0000			
DIZZINES	0.6686	0.3973	0.4026	-0.3922	0.6755	0.4651	0.3838	0.1078	1.0000		
VISUAL DIFFICULTY	0.8271	0.7564	0.6886	-0.5383	0.5818	0.6359	0.5720	0.0455	0.5556	1.0000	
UNIFORM	0.3028	0.3110	0.1653	-0.1020	0.2438	0.1664	0.2749	-0.0969	0.2487	0.4839	1.0000

Table C-5.

Correlations of questionnaire data: Profile of mood states vs. demographics.

Shaded Correlations Are Significant At p≤ .05

	HEIGHT	WEIGHT	PT SCORE	HEAT STRESS TRAINING	TOTAL FIGHT TIME	UH60 FLIGHT TIME	TOTAL SIMULATED FLIGHT	UNIFORM	TEMPERATURE	PRE VIGOR	PRE ANGER-HOSTILITY	PRE FATIGUE	PRE TENSION-ANXIETY	PRE CONFUSION-BEWILDERMENT	PRE DEPRESSION-DEJECTION	PRE TOTAL MOOD DISTURBANCE	POST VIGOR	POST ANGER-HOSTILITY	POST FATIGUE	POST TENSION-ANXIETY	POST CONFUSION-BEWILDERMENT	POST DEPRESSION-DEJECTION	POST TOTAL MOOD DISTURBANCE	AGE
HEIGHT	1.0000																							
WEIGHT	0.6377	1.0000																						
PT SCORE	-0.3617	-0.4562	1.0000																					
HEAT STRESS TRAINING	0.2818	-0.0928	-0.2231	1.0000																				
TOTAL FIGHT TIME	0.1047	0.1147	-0.2767	0.5505	1.0000																			
UH60 FLIGHT TIME	-0.3343	-0.0615	0.1353	-0.1977	0.0892	1.0000																		
TOTAL SIMULATED FLIGHT	-0.3278	-0.1330	0.1694	-0.0518	0.0490	0.8743	1.0000																	
UNIFORM	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000																
TEMPERATURE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000															
PRE VIGOR	-0.0708	-0.0026	-0.0654	-0.1668	-0.0516	-0.1450	-0.3054	0.0579	-0.0927	1.0000														
PRE ANGER-HOSTILITY	0.2633	0.1602	0.4053	-0.1070	0.0700	-0.2455	-0.2342	-0.0183	0.1074	-0.1394	1.0000													
PRE FATIGUE	0.0949	0.0254	0.4391	-0.1886	0.0846	-0.0764	-0.1139	-0.0254	-0.0085	-0.2264	0.7792	1.0000												
PRE TENSION-ANXIETY	0.1547	-0.0572	0.2772	0.1642	0.1482	-0.0650	0.0714	0.0036	0.2619	-0.4805	0.6342	0.5537	1.0000											
PRE CONFUSION-BEWILDERMENT	0.3108	0.1445	0.3048	0.0038	0.1113	-0.1764	-0.1474	0.0208	0.0623	-0.3610	0.7821	0.7847	0.7656	1.0000										
PRE DEPRESSION-DEJECTION	0.1299	0.0646	0.4950	-0.1726	-0.0229	-0.1039	-0.0251	-0.0250	0.1035	-0.2122	0.8822	0.7715	0.7463	0.8286	1.0000									
PRE TOTAL MOOD DISTURBANCE	0.2090	0.0715	0.4049	-0.0216	0.0881	-0.1042	-0.0192	-0.0255	0.1348	-0.5209	0.8661	0.8259	0.8556	0.9085	0.9037	1.0000								
POST VIGOR	0.2329	0.3866	-0.0379	-0.1615	-0.0657	-0.2328	-0.3624	-0.2971	-0.2472	0.6168	0.0712	-0.0737	-0.3454	-0.1356	-0.0308	-0.2436	1.0000							
POST ANGER-HOSTILITY	0.1687	0.1725	0.4102	-0.0718	0.1479	0.0200	0.1328	0.0637	0.1912	-0.2548	0.7542	0.6288	0.5448	0.6134	0.7451	0.7310	-0.1402	1.0000						
POST FATIGUE	-0.1001	-0.1788	0.1846	-0.1453	0.1236	0.1758	0.1700	0.4260	0.4424	-0.0860	0.2623	0.3691	0.3717	0.3008	0.3127	0.3397	-0.5614	0.4306	1.0000					
POST TENSION-ANXIETY	0.0241	-0.1143	0.1652	0.2979	0.2229	0.1884	0.4115	0.2201	0.2115	-0.5317	0.2086	0.2847	0.5302	0.4200	0.2942	0.4675	-0.6064	0.5068	0.5348	1.0000				
POST CONFUSION-BEWILDERMENT	0.1946	0.0890	0.2874	-0.0221	0.1031	0.0652	0.2023	0.2303	0.3040	-0.3271	0.5433	0.5524	0.6427	0.6493	0.6362	0.6801	-0.4276	0.7775	0.7283	0.6814	1.0000			
POST DEPRESSION-DEJECTION	0.1204	0.0894	0.3648	0.0418	0.1426	0.0419	0.1925	0.1338	0.2362	-0.2717	0.5319	0.5248	0.5324	0.5741	0.6320	0.6244	-0.2918	0.6771	0.5135	0.6262	0.8343	1.0000		
POST TOTAL MOOD DISTURBANCE	0.0139	-0.0882	0.3029	0.0425	0.1642	0.1564	0.3048	0.2939	0.3480	-0.4351	0.4566	0.5021	0.6065	0.5442	0.5431	0.6334	-0.6541	0.7705	0.7967	0.8048	0.9138	0.8561	1.0000	
AGE	-0.2116	0.1917	-0.0932	-0.4374	0.3195	-0.0609	-0.0839	0.0000	0.0000	0.1294	0.3408	0.3617	0.0983	0.2432	0.3587	0.2518	0.1110	0.3140	0.2420	-0.0121	0.2161	0.2123	0.1820	1.0000

Table C-6.
Correlations of questionnaire data: Task load index vs. demographics.

Shaded Correlations Are Significant At p≤ .05

	HEIGHT	WEIGHT	PT SCORE	HEAT STRESS TRAINING	TOTAL FIGHT TIME	UH60 FLIGHT TIME	TOTAL SIMULATED FLIGHT	UNIFORM	TEMPERATURE	MENTAL DEMAND	PHYSICAL DEMAND	TEMPORAL DEMAND	PERFORMANCE	EFFORT	FRUSTRATION	AGE
HEIGHT	1.0000															
WEIGHT	0.6366	1.0000														
PT SCORE	-0.3556	-0.4539	1.0000													
HEAT STRESS TRAINING	0.2402	-0.1125	-0.2091	1.0000												
TOTAL FIGHT TIME	0.0776	0.1042	-0.2652	0.5164	1.0000											
UH60 FLIGHT TIME	-0.3306	-0.0587	0.1314	-0.1902	0.1070	1.0000										
TOTAL SIMULATED FLIGHT	-0.3265	-0.1315	0.1674	-0.0449	0.0591	0.8743	1.0000									
UNIFORM	-0.0146	-0.0068	0.0102	-0.0353	-0.0326	0.0068	0.0039	1.0000								
TEMPERATURE	-0.0146	-0.0068	0.0102	-0.0353	-0.0326	0.0068	0.0039	-0.0152	1.0000							
MENTAL DEMAND	0.0150	-0.3189	0.1508	0.0768	0.0152	0.2723	0.4765	0.1339	0.1407	1.0000						
PHYSICAL DEMAND	0.1336	-0.2388	-0.0126	0.3273	0.1893	0.0597	0.1399	0.1891	0.2421	0.7005	1.0000					
TEMPORAL DEMAND	0.4584	0.0483	-0.0569	0.2447	0.1000	-0.3115	-0.3256	0.0636	0.1481	0.4938	0.6573	1.0000				
PERFORMANCE	-0.1233	-0.1823	-0.4239	-0.0462	0.0848	0.0265	-0.0046	-0.0440	0.1526	0.2412	0.3060	0.2319	1.0000			
EFFORT	0.1392	-0.2232	0.1749	0.1047	0.0209	0.2172	0.3946	0.0964	0.1552	0.8995	0.7453	0.6204	0.2767	1.0000		
FRUSTRATION	0.0272	0.0027	-0.0125	0.4629	0.5296	0.2786	0.3483	0.0021	0.2162	0.2832	0.4949	0.1869	0.2896	0.3511	1.0000	
AGE	-0.2064	0.1956	-0.0986	-0.4387	0.3470	-0.0644	-0.0860	0.0074	0.0074	-0.1140	-0.2064	-0.1453	0.1457	-0.1494	-0.0568	1.0000

Table C-7.

Correlations of questionnaire data: Mood and symptoms vs. demographics.

Shaded Correlations Are Significant At p≤ .05

	HEIGHT	WEIGHT	PT SCORE	HEAT STRESS TRAINING	TOTAL FIGHT TIME	UH60 FLIGHT TIME	TOTAL SIMULATED FLIGHT	UNIFORM	TEMPERATURE	HEADACHE	NAUSEA
HEIGHT	1.0000										
WEIGHT	0.6377	1.0000									
PT SCORE	-0.3617	-0.4562	1.0000								
HEAT STRESS TRAINING	0.2618	-0.0928	-0.2231	1.0000							
TOTAL FIGHT TIME	0.1047	0.1147	-0.2767	0.5505	1.0000						
UH60 FLIGHT TIME	-0.3343	-0.0615	0.1353	-0.1977	0.0892	1.0000					
TOTAL SIMULATED FLIGHT	-0.3278	-0.1330	0.1694	-0.0518	0.0490	0.8743	1.0000				
UNIFORM	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000			
TEMPERATURE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000		
HEADACHE	-0.0068	-0.0556	0.0673	0.1455	-0.0027	0.1981	0.2622	-0.0025	0.5762	1.0000	
NAUSEA	0.1222	-0.0122	0.2853	0.1282	0.1552	-0.2398	-0.2112	0.1761	0.2705	0.4488	1.0000
STRESS	0.1358	0.0846	0.1200	0.3941	0.4510	0.0834	0.2276	0.1716	0.3301	0.5451	0.6943
ANGER	0.3165	0.1705	0.0901	0.3178	0.4158	-0.1584	-0.1036	0.0214	0.3470	0.3884	0.7384
DEPRESS	0.2940	0.1554	0.0977	0.3756	0.4773	-0.1693	-0.1155	0.1628	0.2115	0.3145	0.7846
ENERGY	0.2420	0.0316	-0.0643	-0.0337	-0.2637	-0.2810	-0.3094	-0.1644	-0.1078	-0.4080	-0.4060
HEAT STRESS	0.0979	0.0374	0.0487	0.2283	0.3131	0.1149	0.2239	0.6548	0.2941	0.4514	0.5522
THIRST	-0.1277	-0.2777	0.1801	0.2083	0.3262	0.2529	0.4107	0.3055	0.2305	0.5110	0.4717
WORKLOAD	-0.0597	-0.2662	0.3087	0.1577	0.1522	0.0964	0.2381	0.2033	0.3816	0.5000	0.5713
BOREDOM	0.5810	0.5629	-0.3520	0.0821	0.0413	0.1091	0.1067	-0.0278	-0.0793	0.1096	0.1411
DIZZINES	0.1004	0.0007	0.0470	0.3087	0.2244	0.0283	0.1377	0.2823	0.2752	0.5208	0.6134
VISUAL DIFFICULTY	0.0941	0.0226	0.1879	0.1970	0.3361	0.0519	0.1577	-0.0273	0.4978	0.6280	0.6506
AGE	-0.2116	0.1917	-0.0932	-0.4374	0.3195	-0.0609	-0.0839	0.0000	0.0000	-0.1680	0.1884

	STRESS	ANGER	DEPRESS	ENERGY	HEAT STRESS	THIRST	WORKLOAD	BOREDOM	DIZZINES	VISUAL DIFFICULTY	AGE
STRESS	1.0000										
ANGER	0.7628	1.0000									
DEPRESS	0.7676	0.8634	1.0000								
ENERGY	-0.6102	-0.3444	-0.3140	1.0000							
HEAT STRESS	0.7670	0.5169	0.6029	-0.4845	1.0000						
THIRST	0.7210	0.4129	0.5204	-0.5458	0.7608	1.0000					
WORKLOAD	0.6797	0.6196	0.5450	-0.3013	0.6569	0.6579	1.0000				
BOREDOM	0.1411	0.2637	0.2102	-0.1753	0.1057	-0.0492	-0.1162	1.0000			
DIZZINES	0.6681	0.4971	0.5961	-0.3706	0.6798	0.5583	0.5374	0.0686	1.0000		
VISUAL DIFFICULTY	0.8425	0.7861	0.6602	-0.5285	0.5957	0.6466	0.6702	0.0561	0.5480	1.0000	
AGE	0.1321	0.1376	0.1277	-0.3155	0.1172	0.1159	0.0488	-0.0721	-0.0366	0.1664	1.0000

Table C-8.

Correlations of questionaire data: Profile of mood states vs. physiological.

Shaded Correlations Are Significant At p≤ .05

	MAX CORE TEMP	SWEAT LOSS PER HOUR	% DEHYDRATION	SKIN TEMPERATURE	ARM TEMPERATURE	CHEST TEMPERATURE	THIGH TEMPERATURE	LEG TEMPERATURE	PRE VIGOR	PRE ANGER-HOSTILITY	PRE FATIGUE	PRE TENSION-ANXIETY	PRE CONFUSION-BEWILDERMENT	PRE DEPRESSION-DEJECTION	PRE TOTAL MOOD DISTURBANCE	POST VIGOR	POST ANGER-HOSTILITY	POST FATIGUE	POST TENSION-ANXIETY	POST CONFUSION-BEWILDERMENT	POST DEPRESSION-DEJECTION	POST TOTAL MOOD DISTURBANCE	MAX HEART RATE
MAX CORE TEMP	1.0000																						
SWEAT LOSS PER HOUR	0.7511	1.0000																					
% DEHYDRATION	0.5340	0.6886	1.0000																				
SKIN TEMPERATURE	0.8300	0.7350	0.5020	1.0000																			
ARM TEMPERATURE	0.6248	0.6112	0.4059	0.8379	1.0000																		
CHEST TEMPERATURE	0.6242	0.5922	0.3728	0.8314	0.5055	1.0000																	
THIGH TEMPERATURE	0.7677	0.7052	0.5216	0.9525	0.7231	0.7697	1.0000																
LEG TEMPERATURE	0.7545	0.6960	0.4717	0.9231	0.6744	0.7390	0.8819	1.0000															
PRE VIGOR	0.0346	0.0333	-0.0485	0.0392	-0.0046	-0.0268	0.0567	0.1162	1.0000														
PRE ANGER-HOSTILITY	0.0552	0.1156	0.3201	-0.0226	0.0523	-0.0244	-0.0037	-0.1262	-0.1403	1.0000													
PRE FATIGUE	-0.0777	0.0577	0.2732	-0.1234	-0.0545	-0.1120	-0.1171	-0.1666	-0.2236	0.8030	1.0000												
PRE TENSION-ANXIETY	0.1591	0.1962	0.3700	0.0981	0.0702	0.1515	0.0948	0.0375	-0.4819	0.6358	0.5670	1.0000											
PRE CONFUSION-BEWILDERMENT	0.0711	0.1651	0.3830	-0.0279	-0.0041	-0.0079	-0.0397	-0.0485	-0.3629	0.7903	0.7936	0.7675	1.0000										
PRE DEPRESSION-DEJECTION	0.0504	0.1361	0.4150	-0.0295	0.0241	-0.0140	-0.0233	-0.1041	-0.2178	0.8826	0.8025	0.7491	0.8366	1.0000									
PRE TOTAL MOOD DISTURBANCE	0.0460	0.1241	0.3605	-0.0270	0.0250	0.0078	-0.0262	-0.1128	-0.5213	0.8679	0.8379	0.8565	0.9111	0.9081	1.0000								
POST VIGOR	-0.3213	-0.2525	-0.1038	-0.3355	-0.2440	-0.3987	-0.2555	-0.3195	0.6154	0.0757	-0.0712	-0.3500	-0.1421	-0.0354	-0.2441	1.0000							
POST ANGER-HOSTILITY	0.0709	0.3000	0.3772	0.0464	0.0689	0.0448	0.0899	-0.0561	-0.2572	0.7506	0.6563	0.5451	0.6233	0.7433	0.7331	-0.1376	1.0000						
POST FATIGUE	0.5388	0.5599	0.5181	0.4952	0.3581	0.4584	0.4701	0.4855	-0.0786	0.3002	0.3922	0.3982	0.3223	0.3555	0.3678	-0.5670	0.4779	1.0000					
POST TENSION-ANXIETY	0.2608	0.4026	0.3916	0.1902	0.1159	0.2009	0.1775	0.1935	-0.5381	0.2066	0.3027	0.5321	0.4237	0.2902	0.4704	-0.6181	0.5076	0.5684	1.0000				
POST CONFUSION-BEWILDERMENT	0.2772	0.4519	0.5257	0.2082	0.1441	0.1871	0.2234	0.1864	-0.3237	0.5661	0.5672	0.6551	0.6625	0.6636	0.6953	-0.4215	0.8067	0.7229	0.6985	1.0000			
POST DEPRESSION-DEJECTION	0.1065	0.4318	0.4011	0.0856	0.0682	0.0846	0.1163	0.0284	-0.2703	0.5309	0.5497	0.5340	0.5846	0.6348	0.6278	-0.2839	0.8797	0.5342	0.6292	0.8469	1.0000		
POST TOTAL MOOD DISTURBANCE	0.3313	0.4946	0.4657	0.2935	0.2183	0.2997	0.2843	0.2469	-0.4329	0.4637	0.5207	0.6133	0.5555	0.5549	0.6409	-0.6491	0.7819	0.8101	0.8149	0.9171	0.8573	1.0000	
MAX HEART RATE	0.6637	0.6225	0.3518	0.6762	0.5470	0.6030	0.6572	0.5941	0.1843	-0.1609	-0.3074	-0.0251	-0.2077	-0.2134	-0.2207	-0.1196	-0.0761	0.2447	0.1082	0.0522	-0.0072	0.0929	1.0000

Table C-9.

Correlations of questionaire data: Task load index vs. physiological.

Shaded Correlations Are Significant At p≤ .05

	MAX CORE TEMP	SWEAT LOSS PER HOUR	% DEHYDRATION	SKIN TEMPERATURE	ARM TEMPERATURE	CHEST TEMPERATURE	THIGH TEMPERATURE	LEG TEMPERATURE	MENTAL DEMAND	PHYSICAL DEMAND	TEMPORAL DEMAND	PERFORMANCE	EFFORT	FRUSTRATION	MAX HEART RATE
MAX CORE TEMP	1.0000														
SWEAT LOSS PER HOUR	0.7979	1.0000													
% DEHYDRATION	0.5328	0.7235	1.0000												
SKIN TEMPERATURE	0.8309	0.7574	0.4993	1.0000											
ARM TEMPERATURE	0.6239	0.6321	0.4030	0.8368	1.0000										
CHEST TEMPERATURE	0.8242	0.6101	0.3696	0.8301	0.5022	1.0000									
THIGH TEMPERATURE	0.7686	0.7209	0.5190	0.9520	0.7210	0.7679	1.0000								
LEG TEMPERATURE	0.7545	0.7188	0.4688	0.9224	0.6719	0.7370	0.8808	1.0000							
MENTAL DEMAND	0.2259	0.0976	-0.0144	0.1451	0.0395	0.2358	0.1286	0.1379	1.0000						
PHYSICAL DEMAND	0.3336	0.2168	0.1505	0.2477	0.0672	0.3382	0.2444	0.2669	0.6860	1.0000					
TEMPORAL DEMAND	0.1491	0.0596	-0.1129	0.1012	0.0552	0.0994	0.1106	0.0983	0.4611	0.6366	1.0000				
PERFORMANCE	0.1216	-0.1451	-0.0812	0.1146	0.0484	0.2754	-0.0023	0.1279	0.2331	0.2993	0.2223	1.0000			
EFFORT	0.2082	0.0948	0.0323	0.1338	0.0269	0.2821	0.1005	0.0991	0.8948	0.7340	0.5991	0.2698	1.0000		
FRUSTRATION	0.0517	0.0861	0.2430	0.0489	-0.0144	0.1359	0.0860	-0.0243	0.2680	0.4848	0.1586	0.2859	0.3388	1.0000	
MAX HEART RATE	0.6639	0.6289	0.3475	0.6720	0.5430	0.5993	0.6522	0.5895	-0.0523	0.1350	-0.0626	-0.0183	-0.1200	0.1001	1.0000

Table C-10.

Correlations of questionaire data: Mood symptoms vs. physiological.

Shaded Correlations Are Significant At $p \leq .05$

	MAX CORE TEMP	SWEAT LOSS PER HOUR	% DEHYDRATION	SKIN TEMPERATURE	ARM TEMPERATURE	CHEST TEMPERATURE	THIGH TEMPERATURE	LEG TEMPERATURE	HEADACHE	NAUSEA	STRESS	ANGER	DEPRESS	ENERGY	HEAT STRESS	THIRST	WORKLOAD	BOREDOM	DIZZINES	VISUAL DIFFICULTY	MAX HEART RATE
MAX CORE TEMP	1.0000																				
SWEAT LOSS PER HOUR	0.7511	1.0000																			
% DEHYDRATION	0.5340	0.6886	1.0000																		
SKIN TEMPERATURE	0.8300	0.7350	0.5020	1.0000																	
ARM TEMPERATURE	0.6248	0.6112	0.4059	0.8379	1.0000																
CHEST TEMPERATURE	0.8242	0.5922	0.3728	0.8314	0.5055	1.0000															
THIGH TEMPERATURE	0.7677	0.7052	0.5216	0.9525	0.7231	0.7697	1.0000														
LEG TEMPERATURE	0.7545	0.6960	0.4717	0.9231	0.6744	0.7390	0.8819	1.0000													
HEADACHE	0.3766	0.3313	0.4093	0.2925	0.2081	0.3764	0.2701	0.1997	1.0000												
NAUSEA	0.2791	0.4241	0.4822	0.2140	0.1900	0.2011	0.2068	0.1584	0.4772	1.0000											
STRESS	0.1999	0.4543	0.5175	0.1919	0.1662	0.1548	0.2066	0.1460	0.5725	0.6930	1.0000										
ANGER	0.1071	0.3042	0.3085	0.1021	0.1086	0.1013	0.1430	-0.0056	0.4133	0.7346	0.7623	1.0000									
DEPRESS	0.1046	0.4227	0.3483	0.1519	0.1350	0.1124	0.1881	0.0913	0.3340	0.7819	0.7668	0.8615	1.0000								
ENERGY	-0.0415	-0.1904	-0.3433	-0.1070	-0.1810	-0.0361	-0.0505	-0.0975	-0.4021	-0.4134	-0.6173	-0.3524	-0.3204	1.0000							
HEAT STRESS	0.5462	0.6937	0.6119	0.6288	0.4961	0.4821	0.6227	0.6289	0.4887	0.5494	0.7665	0.5131	0.6012	-0.4932	1.0000						
THIRST	0.2993	0.4182	0.3788	0.3106	0.1656	0.3345	0.3137	0.3106	0.5316	0.4759	0.7263	0.4176	0.5249	-0.5529	0.7739	1.0000					
WORKLOAD	0.4158	0.4726	0.4452	0.3217	0.1897	0.4082	0.2988	0.2717	0.5441	0.5641	0.6829	0.5077	0.5374	-0.3135	0.6549	0.6807	1.0000				
BOREDOM	-0.0225	-0.0601	0.0412	-0.0773	-0.0134	-0.0678	-0.0997	-0.1005	0.1242	0.1216	0.1299	0.2448	0.1933	-0.1828	0.0888	-0.0494	-0.1693	1.0000			
DIZZINESS	0.3318	0.5831	0.4655	0.3066	0.2447	0.2731	0.2796	0.2962	0.5480	0.6100	0.6685	0.4919	0.5924	-0.3767	0.6801	0.5615	0.5344	0.0531	1.0000		
VISUAL DIFFICULTY	0.1480	0.3298	0.4712	0.1449	0.1432	0.1447	0.1838	0.0280	0.6419	0.8571	0.8456	0.7947	0.6658	-0.5298	0.6010	0.6506	0.6893	0.0577	0.5512	1.0000	
MAX HEART RATE	0.6637	0.6225	0.3518	0.6762	0.5470	0.6030	0.6572	0.5941	0.2967	0.1343	0.1310	0.0976	0.0823	0.1199	0.3661	0.0919	0.1596	-0.1716	0.3698	0.1047	1.0000

Table C-11.
Correlations of time in MOPP4 100°F condition vs. demographics.

Marked correlations are significant at $p < .05000$
N=17 (Casewise deletion of missing data)

	AGE	HEIGHT	WEIGHT	PT SCORE	HEAT STRESS TRAINING	TOTAL FLIGHT TIME	UH60 FLIGHT	TOTAL SIM. FLIGHT TIME	TIME IN UNIFORM
AGE	1								
HEIGHT	-0.21162	1							
WEIGHT	0.191692	0.637688	1						
PT SCORE	-0.09319	-0.36166	-0.45616	1					
HEAT STRESS TRAINING	-0.43738	0.261809	-0.0928	-0.22313	1				
TOTAL FLIGHT TIME	0.319506	0.104669	0.114657	-0.27668	0.550454	1			
UH60 FLIGHT	-0.06088	-0.33428	-0.0615	0.135323	-0.19768	0.089222	1		
TOTAL SIM. FLIGHT TIME	-0.08391	-0.32781	-0.13299	0.169381	-0.05185	0.049006	0.874291	1	
TIME IN UNIFORM	0.13391	-0.21245	-0.25298	0.387493	-0.33296	-0.35937	0.216287	0.396921	1

Appendix D. Test Session Run Identifiers

Simulator Test Session Run Identifier

Fields 1-2: The two digit number of the test subject in the right hand pilot seat

Fields 3-4: The two digit number for the day ranging from 01-21

Field 5: The one digit number for the run

Field 6: The one letter designation for the temperature
C= moderate temperature
H= hot temperature
T= training

Field 7: The one letter designation for the uniform
S= standard, ABDU uniform
M= MOPP4, encumbered, current Air Warrior ensemble

Field 8: The one letter designation for the profile
A= air assault
M= medevac

Field 9-10: The two digit number of the test subject in the left hand pilot seat
99 = no one in this seat

Time Stamps:
0 = pilot is flying
1= copilot is flying
2= pilot mask off
3= pilot mask on
4= copilot mask off
5= copilot mask on
9= crash
(Effective 04-24-96)

The ten-place alphanumeric simulator test session run identifier was entered into the VAX by the simulator operator for physiological and flight performance data collection. The run identifier was associated with the Hawk marker files and was used to query and generate segment files for data analysis. Fields 1 and 2 represent the test subject in the pilot seat. Fields 3 and 4 represent the day of testing or training. Field 5 is the run number. Field 6 is the one letter designation for the temperature condition. Field 7 is the one letter representation of the uniform condition. Field 8 is the one letter designation for the flight scenario. Fields 9 and 10 represent the test subject in the co-pilot's seat. In addition to the run identifier, time stamps were also entered by the simulator operator to indicate when controls were changed out during nonstandard maneuvers, when the pilots removed or replaced their mask, and when crashes occurred.

Appendix E. Questionnaires

AIR WARRIOR TASK LOAD INDEX QUESTIONNAIRE

v 4/26/96

Today's Date:__________ Test Subject No. ______

❑ Instructions:
1. Administer the series of questions as indicated by the flight profiles.
2. Alert test subject "TEST SUBJECT NAME, TLX QUESTIONAIRE".
3. Wait for acknowledgement, then go through the questions using the same pace, wording, and inflection for each administration.
4. Record results in appropriate locations.

	QUESTION	SCALE		RATINGS*							
	On a scale of 0 to 10 please assess your experience related to (appropiate activity) of the following conditions:		Timer time								
1	mental demand	(0 =low	10=high)								
2	physical demand	(0 =low	10=high)								
3	temporal demand	(0=low	10=high)								
4	performance	(0=good	10=poor)								
5	effort	(0=low	10=high)								
6	frustration	(0=low	10=high)								
			Technicians initials--								

*data entered on template in correct TLX scale

NAME ______________________ DATE __________

SEX: Male (M) Female (F)

IDENTIFICATION

Below is a list of words that describe feelings people have. Please read each one carefully. Then fill in ONE circle under the answer to the right which best describes HOW YOU ARE FEELING RIGHT NOW.

The numbers refer to these phrases.

0 = Not at all
1 = A little
2 = Moderately
3 = Quite a bit
4 = Extremely

Col (C) O.P. (O)

Item	NOT AT ALL	A LITTLE	MODERATELY	QUITE A BIT	EXTREMELY
1. Friendly	0	1	2	3	4
2. Tense	0	1	2	3	4
3. Angry	0	1	2	3	4
4. Worn out	0	1	2	3	4
5. Unhappy	0	1	2	3	4
6. Clear-headed	0	1	2	3	4
7. Lively	0	1	2	3	4
8. Confused	0	1	2	3	4
9. Sorry for things done	0	1	2	3	4
10. Shaky	0	1	2	3	4
11. Listless	0	1	2	3	4
12. Peeved	0	1	2	3	4
13. Considerate	0	1	2	3	4
14. Sad	0	1	2	3	4
15. Active	0	1	2	3	4
16. On edge	0	1	2	3	4
17. Grouchy	0	1	2	3	4
18. Blue	0	1	2	3	4
19. Energetic	0	1	2	3	4
20. Panicky	0	1	2	3	4
21. Hopeless	0	1	2	3	4
22. Relaxed	0	1	2	3	4
23. Unworthy	0	1	2	3	4
24. Spiteful	0	1	2	3	4
25. Sympathetic	0	1	2	3	4
26. Uneasy	0	1	2	3	4
27. Restless	0	1	2	3	4
28. Unable to concentrate	0	1	2	3	4
29. Fatigued	0	1	2	3	4
30. Helpful	0	1	2	3	4
31. Annoyed	0	1	2	3	4
32. Discouraged	0	1	2	3	4
33. Resentful	0	1	2	3	4
34. Nervous	0	1	2	3	4
35. Lonely	0	1	2	3	4
36. Miserable	0	1	2	3	4
37. Muddled	0	1	2	3	4
38. Cheerful	0	1	2	3	4
39. Bitter	0	1	2	3	4
40. Exhausted	0	1	2	3	4
41. Anxious	0	1	2	3	4
42. Ready to fight	0	1	2	3	4
43. Good natured	0	1	2	3	4
44. Gloomy	0	1	2	3	4
45. Desperate	0	1	2	3	4
46. Sluggish	0	1	2	3	4
47. Rebellious	0	1	2	3	4
48. Helpless	0	1	2	3	4
49. Weary	0	1	2	3	4
50. Bewildered	0	1	2	3	4
51. Alert	0	1	2	3	4
52. Deceived	0	1	2	3	4
53. Furious	0	1	2	3	4
54. Efficient	0	1	2	3	4
55. Trusting	0	1	2	3	4
56. Full of pep	0	1	2	3	4
57. Bad-tempered	0	1	2	3	4
58. Worthless	0	1	2	3	4
59. Forgetful	0	1	2	3	4
60. Carefree	0	1	2	3	4
61. Terrified	0	1	2	3	4
62. Guilty	0	1	2	3	4
63. Vigorous	0	1	2	3	4
64. Uncertain about things	0	1	2	3	4
65. Bushed	0	1	2	3	4

MAKE SURE YOU HAVE ANSWERED EVERY ITEM.

POM 021

AIR WARRIOR MOOD AND SYMPTOMS QUESTIONNAIRE
v 4/26/96

Today's Date:__________ Test Subject No. ____

❑ Instructions:
1. Administer the series of questions at the following times: Just prior to simulated pre-flight, 15 minutes into simulated pre-flight and at times indicated in flight profile.
2. Alert the test subject with the following :"Test subjects name, Mood and symptoms questionnaire "
3. Go through the questions using the same pace, wording, and inflection for each administration.
4. Record results in appropriate locations.

QUESTION | SCALE | RATINGS AT 30 MIN INTERVALS

	On a scale of 0 to 10 please rate your sensation of:	Timer Time (Hrs:mins)--->												
1	headache	(0 = none 10 = very severe)												
2	nausea	(0 = none 10 = about to vomit)												
3	stress	(0 = none 10 = very severe, can't take it)												
4	anger	(0 = none 10 = extremely)												
5	depression	(0 = none 10 = extremely)												
6	energy	(0 = none 10 = a lot)												
7	heat stress	(0 = none 10 = unbearable)												
8	thirst	(0 = none 10 = severe)												
9	workload	(0 = very light 10 = overwhelming)												
10	boredom	(0 = none 10 = totally boring)												
11	dizziness	(0 = none 10 = very severe)												
12	visual difficulty	(0 = none 10 = can hardly see)												
13	hot spots location:	(0 = none 10 = a lot) ____________ ____________ ____________ ____________												
		Technician initials --->												

esq1.frm

Appendix F. Data Collection Forms

AIR WARRIOR TS WEIGHT & FLUID BALANCE WORKSHEET (rev.04-23-96)

Today's Date: ____________ Test Subject No.: _____

Uniform: ① standard flight ② Air Warrior

Activity: ① training/acclimatizing ② testing

Environmental condition: ① moderate (70°F, 50%rh) ② hot (100°F, 50%rh)

→PRETEST:	→POSTTEST:
❑ Nude weight _______ kg ❑ Clothed & instrumented weight: _______ kg	❑ Clothed & instrumented weight: _______ kg ❑ Nude weight _______ kg

→ URINE OUTPUT: (Formula Number 7)

Formula Number	Time of urination	Empty Specimen Container Wgt (kg)	Full Specimen Container Wgt (kg)	Full Wgt - Empty Wgt (kg)
10	After pre-clothed			
	After post-nude			

→ FLUID INTAKE: (Formula Number 5)

Formula Number	Time of intake	Fluid Container Label Name or #	Initial Wgt (kg)	Final Wgt (kg)	Initial - Final (kg)
	After pre-nude				
8	After pre-clothed				
8					
8					
	After post-clothed				

→ FOOD INTAKE: (Formula Number 6 and 9)

Type of Food	Initial Wgt (kg)	Final Wgt (kg)	Initial - Final (kg)

AIR WARRIOR TS MONITORING & BACKUP DATA COLLECTION FORM

Today's Date: ____________ Test Subject No.: _____

Uniform: ① standard flight ② Air Warrior

Activity: ① training/acclimatizing ② testing

Environmental condition: ① moderate (70°F, 50%rh) ② hot (100°F, 50%rh)

Estimated max heart rate: _____ 90% max: _____ 80% max: ____

Entry #	Clock time	Timer time	Cabin temp (°F)	RH %	Heart rate	Core temp (°C)	Test Subject Activity	Comments

Enter heart rate & core temp every 10 mins. Limits: core temp =102.5F (39.2C), heart rate not more than 90% of predicted max.

Appendix G. Checklists and Procedures

Sensor application proceedure

1.Apply Benzion to area of chest where first sensor is to be placed.
2.Make a loop in sensor lead and tape down approx. 2" from where sensor is to be placed.
3.While holding sensor in place with a cotton swab,pour a small amount of Colloidon on and around the sensor.
4.Using the air pump, air dry the Colloidon.When dry tape down the sensor.
5.Repeat these proceedures for each sensor,placing the 2nd sensor on the upper arm mid way between the elbow and the shoulder (thread sensor up under T-shirt and out through sleeve),the 3rd on the outside of the thigh mid way between knee and hip,the 4th on the outside of the lower leg on the calf muscle.

6.Place the EKG sensors on the chest ,one on each side of the upper chest and one on the right side of the chest just over the last rib.
7.Attach the leads to the sensors,right arm to the right upper chest,left arm to the left upper chest and right leg tothe right lower chest.

8. Assist the test subject dressing,assuring no leads pull lose.
9. Tape excess wires together leaving ends free to allow for disconnect and reconnect.
10.After placing Squirrel in the carrying case connect leads to the Squirrel.

Air warrior test subject checklist.		
1. TEST SUBJECT EQUIPMENT	**2. VITALS CHECKLIST**	**3. PRETEST HOOK-UP**
COMPLETE FLIGHT SUIT	INITIALS	SET-UP EQUIPMENT(squirrel,cables,cortemp,"R" wave counter)
NBC BOOTS	COMPLETE TEST SUBJECT DATA COLLECTION FORMS	TEST SUBJECT EMPTY BLADDER AND NOTE TIME
NBC OVER GARMENT	BLOOD PRESSURE (Supine & Standing)	TEST SUBJECT INSERT PROBE
WATER WINGS (snug under arm pits)	RESPIRATION	TEST SUBJECT NUDE WEIGHT
CHICKEN PLATE	PULSE/HEART RATE	ADJUST "R" WAVE CABLES
SARVIP (with O_2 bottle,survival knife,pistol,full pouches)	ORIENTATION	APPLY SENSORS
RAFT	ATAXIA	CHECK SQUIRREL READINGS
M431A CB MASK	ORAL TEMPERATURE	AID TEST SUBJECT DRESSING
FLIGHT HELMET	CHECK TEST SUBJECT EQUIPMENT	BEGIN DATA COLLECTION (squirrels & Questionnaire)
		ESCORT TEST SUBJECT TO ENVIRONMENTAL CHAMBER
4. SIMULATOR PREP	**5. ENVIRONMENTAL CHAMBER**	**6. SIMULATOR**
CONNECT BLUE HAWK CABLE	SET UP TREADMILL (0 degrees incline,20 minute interval,3.0mph)	DISCONNECT SQUIRREL CABLE FROM TEST SUBJECT
TURN ON DATA ACQUISITION MONITOR/KEYBOARD	COLLECT DATA AT PRESCRIBED INTERVAL(heart rate,core temp.,relative humidity,chamber temp.)	CONNECT TEST SUBJECT SENSOR CABLE TO VAX
TURN ON CAMERA BOX	OBSERVE TEST SUBJECT FOR HEAT STRESS REACTION	CHECK PATCH CABLE POLARITY
TURN ON T.V. MONITOR	ASK MEDICAL QUESTIONS AT PRESCRIBED INTERVALS	CHECK COMMUNICATIONS HOOK-UP WITH TEST SUBJECT & TECH
TURN ON CPU		INSURE CAMERAS SET TO PROPER ORIENTATION
LOAD MATB VOICE FILES		PT MONITER
LOAD MATB		INSURE TECH IS STRAPPED IN
TEST SOUND		COLLECT DATA FROM D.A.B. AT PRESCRIBED INTERVALS
CHECK SCRIPT		ADMINISTER QUESTIONAIRES (MOODSYS,TLX,) AT PRESCRIBED INTERVALS
CHECK GAIN		CUE START OF MATB AT PRESCRIBED INTERVALS
		OBSERVE TEST SUBJECT
		UNHOOK TEST SUBJECT
7. SIMULATOR POST FLIGHT	**8. RECOVERY ROOM**	**9. POST-TEST CHECKLIST**
PLACE DISKETTE IN "A" DRIVE	CHECK LIFPAK	REMOVE SENSORS
DOWNLOAD MATB DATA FILES	OBTAIN POST TEST WEIGHT CLOTHED	OBTAIN POST TEST CATECHOLAMINE URINE SAMPLE
REMOVE MATB KEYBOARD/MONTIOR	OBTAIN POST TEST CATECHOLAMINE URINE SAMPLE	OBTAIN POST TEST NUDE WEIGHT
TURN OFF T.V.	REHYDRATE TEST SUBJECT	CLEAN PROBES &SENSORS
TURN OFF CAMERA BOX	ADMINSTER POMS	RESTOCK BATH ROOM CART
MAKE SURE ALL MATERIALS ARE OUT OF SIMULATOR		STORE PROBES IN DISINFECTANT
		CLEAN UP & PREPARE LAB FOR NEXT DAY

Appendix H. Manufacturers and Product Information

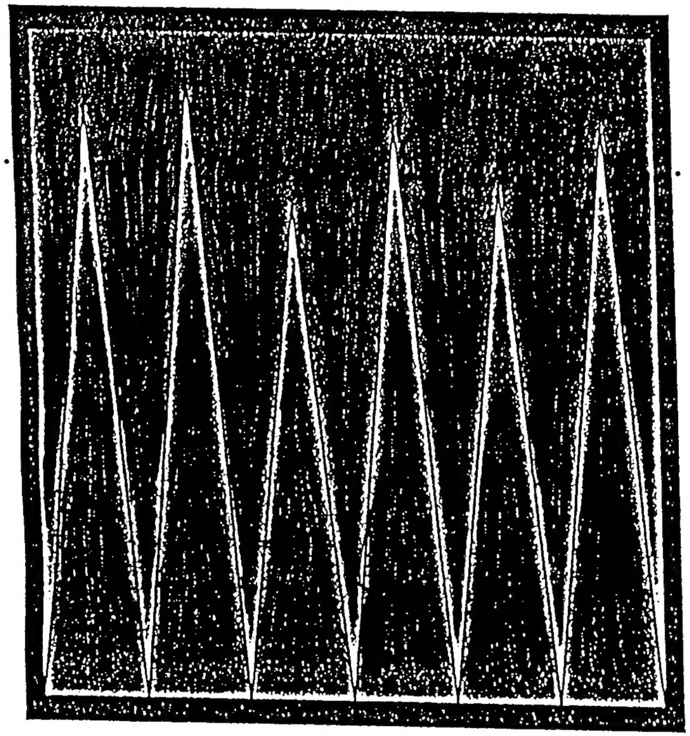
Beckman Industrial Corporation 4200 Bonita Place Fullerton, California 92635	RTD Temperature Probe Calibrator/Indicator
Biosig Instruments, Incorporated P.O. Box 860 Champlain, New York 12919	R-wave Counter
Human Technologies, Incorporated 1325 Snell Isle Boulevard, North East Suite 204 St. Petersburg, Florida 33704	CorTemp System
Microsoft Corporation P.O. Box 72368 Roselle, Illinois 66172-9900	MicroSoft Office Professional
NASA Langley Research Center Hampton, Virginia 23665-5225	Multi-Attribute Task Battery
Precision Sciences Inc 3737 West Courtland Street Chicago, Illinois 60647	Shaking Water Bath
Reuter-Stokes 465 Dobbie Drive Cambridge, Ontario, Canada N1R 5X9	WBGT Logger
Science Electronics P.O. Box 986 Dayton, Ohio 45401	Squirrel (Grant) Data Logger
SPSS Inc 444 North Michigan Avenue Chicago, Illinois 60611	SPSS Statistical Software
Statsoft 2325 East 13th Street Tulsa, Oklahoma 74104	Statistica Software

Unisource Worldwide Inc P.O. Box 958 Valley Forge, Pennsylvania 19482	Mint-A-Dish Disinfectant
Vermont Medical Inc Industrial Park Bellows Falls, Vermont 05101-3122	ECG Pads
Yellow Springs Instrument Company P.O. Box 279 Yellow Springs, Ohio 45387	Rectal and Skin Thermistors

P R E S E N T I N G

C O R T E M P™

98.6



98.6

The new, ingestible thermometer that monitors, records, and reports body core temperature. Assures personal comfort, even during highly-physical activity; guarantees 1/10° C accuracy.

CorTemp Product Specifications

CorTemp™ Ambulatory Recorder

Size:	L 7.5" (190.5mm) W 4.0" (101.6mm) H 2.0" (50.8mm)
Weight:	19.6 oz. (550 gms)
Pick-up Coil (Antenna):	Bandolier style
Power:	9 volt DC: idle current 6 ma; peak operating 52 ma.
Continuous Operating Time:	Battery life/sample rate dependent
Sampling Rate:	User programmable, 30 sec. to hourly
Calibration:	User entered
Display:	Two-line liquid crystal alpha-numeric
Data Entry:	Keyboard
Operating Temperature Range:	10°C - 43°C (5[illegible] 110°F)
Data Storage:	16K RAM
Data/Display/Recording:	Temperature (F[illegible]) Alarms (high/low) Alert tone (on/off)
Data Output:	Serial RS232 a. To IBM comp[illegible]ble computer with optional softw[illegible] and data transfer cable; or, b. To serial print[illegible] with optional cable.
Options:	AC/DC adapter Antenna sizes: Sm., Med., Lg., XLg Bed-pad antenna Software: CorTrac™ and CorGraph™ Serial printers Cables Personal comp[illegible]rs Custom applications

CorTemp™ Bedside Monitor (Pending USFDA Certification)

Size:	L 9.0" (22.66mm) approx. W 8.25" (20.96mm) approx. H 3.6" (9.14mm) approx.
Weight:	3.6 lbs. (1710 gms) approx.

Operating specifications are the same as the Ambulatory Recorder with the following exceptions:

Operating Time:	Unlimited
Display:	LED (temperature only) and LCD
Data Entry:	Keyboard and bar-code light wand

CorTemp™ Disposable Temperature Sensor

Size:	L 0.61" (27mm) approx. Dia. 0.4" (10mm) approx.
Sensor Element:	Crystal
Transmission Method:	Near field magnetic link
Temperature Range:	0° Celsius to +50° Celsius
Accuracy:	+/- 0.1° Celsius
Effective Range:	10" (25cm) min.
Power Source:	Silver oxide mini-battery
Capsule Material:	Dimethyl Polysiloxane (silicone) Complies w/21CFR177.210 & 175.300 USFDA Regulations
Usage:	One-time use only
Patented:	U.S. Patent #4,844,076
Calibration:	Factory calibrated

REPRESENTED BY:

CORTEMP®

The ingestible thermometer that monitors, records, and reports body core temperature with safety, comfort, and accuracy.

HUMAN TECHNOLOGIES, INC.
300 Third Avenue North
St. Petersburg, FL 33701
(813) 823-4600
FAX: (813) 823-7596

CorTemp.™ The thermometer pill that tracks body core temperature safely, more naturally... with the highest degree of accuracy.

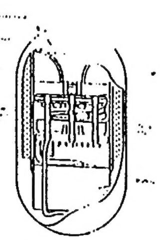
Now, you can track an individual's body core temperature for up to 72 hours without catheters and probes—even in a highly-active environment. Introducing the CorTemp Ingestible thermometer, a technological breakthrough in medical treatment and human research. Among its important clinical advantages, CorTemp:

- ▶ *Requires no catheters, probes, or direct connecting wires*
- ▶ *Enters the gastrointestinal tract safely, gently*
- ▶ *Enables inobtrusive physiological research in high-activity situations*
- ▶ *Enables comfortable bedside monitoring*
- ▶ *Delivers the highest-accuracy readings*
- ▶ *Provides computer compatibility*
- ▶ *Provides inexpensive, long-term service and disposable convenience*

The CorTemp System

The CorTemp system consists of a pill, and either the portable Ambulatory Recorder or the Bedside Monitor.

Packed inside the silicone-coated capsule are a telemetry system, a microbattery, and a quartz crystal temperature sensor. In the gastrointestinal tract, the sensor vibrates at a frequency that varies according to body temperature, producing a magnetic flux and transmitting a signal harmlessly through the body.



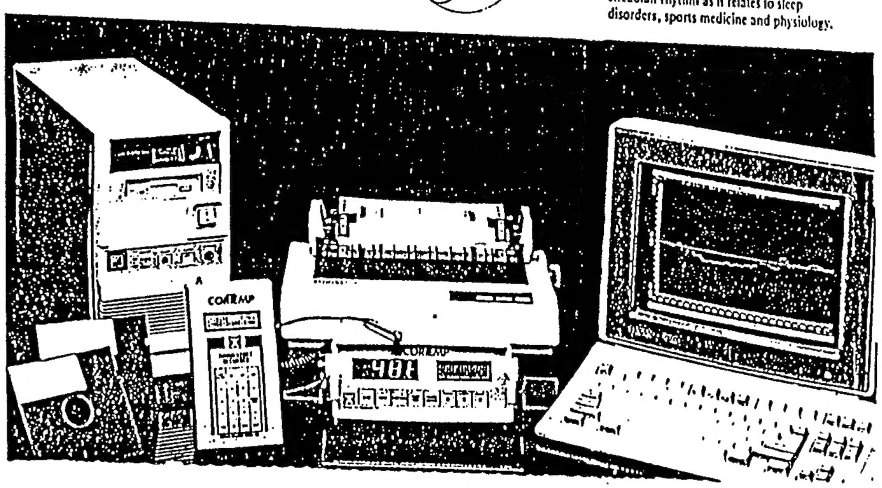
The CorTemp recorder picks up, displays, and stores the data in solid state memory. A clinician can transfer the data to a floppy or hard disk, print a report, or conduct in-depth computer analysis.

The capsule monitors continuously as it travels through the digestive system; clinicians can extend monitoring by administering subsequent pills.

New mobility; new opportunities

Accurate body core temperature reveals vital information for treatment and study. Yet, until now, monitoring in non-laboratory environments proved difficult, if not impossible. With CorTemp, the absence of catheters, probes, and direct wire connectors allows clinicians to monitor the temperature of out-patients and field subjects at home, work, or play; even in highly-active situations.

CorTemp facilitates research, such as the circadian rhythm as it relates to sleep disorders, sports medicine and physiology, metabolism related to obesity, radiation treatments in oncology, gerontology, basal temperature analysis, substance abuse, and more.



And CorTemp brings new comfort to bedside monitoring. In surgery, recovery, ICU, or other resting environments, patients and research subjects can sleep, move, or turn over naturally, without dislodging apparatus or tangling wires.

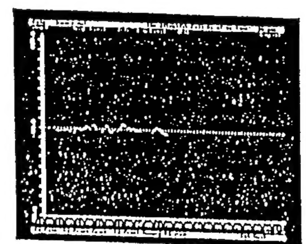
The CorTemp system provides clinicians with programmable options to:

- ▶ *Record and display a patient's temperature in intervals from 30 seconds, up to once an hour*
- ▶ *Record and store up to 4,300 temperature readings*
- ▶ *Record data in Fahrenheit or Celsius*
- ▶ *Sound a tone, warning that the patient's temperature is above or below pre-set limits*
- ▶ *Mark up to 10 different activities (for example, stair-climbing), using the Ambulatory Recorder's 10 event keys*
- ▶ *Plot the current hour's data on the Bedside Monitor for easy trend analysis*

Highly-accurate readings–guaranteed

The CorTemp system provides the highest-quality body core temperature reading available to medicine and human research today. Its quartz crystal sensor vibrates at a frequency in direct proportion to finite changes in body core temperature. The factory-calibrated CorTemp sensor, and high-speed microcomputer, guarantee 1/10° C accuracy throughout the entire temperature range. In non-laboratory environments, ambulatory patients and research subjects—free from discomfort and confinement—yield more reliable data.

In contrast, thermistors require frequent recalibration by clinic personnel. And, the physiological discomfort of thermistors' intrusive probes can distort research findings.



LEFT: Both the Ambulatory Recorder and Bedside Monitor pick up, display, and store body core temperature readings for transfer to your IBM or compatible PC, for printing or computer analysis. ABOVE: Programmable to capture a temperature reading every 30 seconds, up to once an hour, the CorTemp system plots data points to provide a clear view of trends.

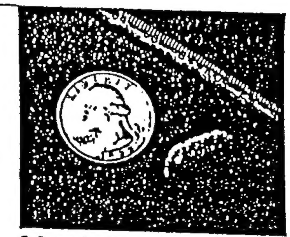
IBM compatibility

CorTemp recorders connect to IBM and compatible PCs and printers, via a standard built-in serial port and optional data transfer cable. Optional software translates and transfers stored data to an ASCII file on a floppy or hard disk, enabling clinicians to print basic data reports and graphs. The ASCII format offers compatibility to the broadest range of specialized, sophisticated applications. Software for custom applications is available on a development contract basis.

Inexpensive, disposable

While its potential in human research is immeasurable, the CorTemp system provides good value to a clinic, research lab, hospital, or physician's office. Both recorder units serve multiple patients and research subjects, going from person to person with no need to autoclave. And CorTemp sensor capsules are inexpensive and disposable.

CorTemp data may be stored on a floppy or hard disk as ASCII files. Custom software development is available.

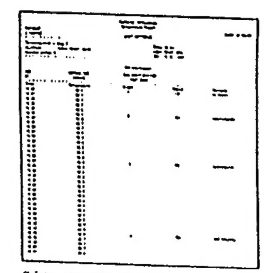


CorTemp packs safety, comfort, and 1/10° C accuracy into a small, 3/4" capsule that has revolutionized temperature monitoring.

Presented by Human Technologies, Inc.

CorTemp's technology was developed by the Johns Hopkins University Applied Physics Laboratory, in collaboration with NASA's Goddard Space Flight Center. First introduced to monitor for hypothermic and hyperthermic body temperatures during space travel, CorTemp recently became available for medical treatment and research applications through Human Technologies, Inc. of St. Petersburg. Founded in 1986, Human Technologies, Inc. is dedicated to the development and manufacture of innovative, high-technology products to improve diagnostic and monitoring capabilities in the advancement of health care and research.

The company is proud to add CorTemp to its growing product line. For details, please contact your Human Technologies, Inc. product representative directly, or call Human Technologies, Inc. for the name of a representative near you.



Print-outs report basic data: Patient or research subject name, pill number, time, temperature reading, event number, and more.

Lamp Recommendations for
Sunlight Simulation

The following equipment is a way to test the effect of solar radiation on equipment for photo-degradation and thermal changes. The spectral output of the electric lamps should simulate the ultraviolet, light, and infrared radiation from sunshine on the terrestrial surface.

This system consists of a bank of HR400RDXFL33 mercury lamps mounted as close as possible to each other and requiring one lamp per square foot of area to be covered. Since these lamps are made with a built-in reflector, a distance of up to 12 feet will be necessary in order to smooth the beam coming from the lamps. The distance should be adjusted until little or no drop-off is observed at the edges of the target.

The spectral distribution for this lamp yields 8% below 400 nm, 46% between 400 nm and 800 nm, with a total radiated output of 135 watts. While this distribution does not quite meet the requirements of MIL-STD-810C, Method 505.1, is comes quite close, being about 25% more severe. It is the closest way we know of to approach the requirements of MIL-STD-810C at a reasonable cost.

The correlated color temperature of the HR400RDSFL33 lamp is 3900k, x = .388, y = .384, initial lumens are 15,500, mean lumens are 9,950 over 24,000 hours rated life. The spectral distribution curve for the lamp is enclosed

Wavelength	Less than 380 nm	Between 380-780	Above 780 nm	Total
MIL-STD-810C Watts/Sq.Ft.	4-7	37.5	50-72	104
HR400RDXFL33 Watts/Sq.Ft.	11	62	62	135

JRM/mos 10/26/90